71-9203

AREVA

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

RDM-06-001

January 20, 2006

ATTN: E. W. Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards,
U.S. Nuclear Regulatory Commission,
Washington, DC 20555-0001

Subject: **Request for Renewal of Certificate of Compliance No. 71-9203 for the Model No. DHTF Package, Reference Letter RDM-05-015, dated 10/05/2005.**

Dear Mr. Brach:

As requested by Ms. Jessica Umaña of your staff, Framatome ANP (FANP), Inc., an AREVA and Siemens Company, is providing as Attachment I, a Consolidated License Application for the DHTF Shipping Container (revision 4) to support the renewal application for the package as submitted on October 5, 2005.

If you or your staff have any questions, require additional information, or wish to discuss the matter further, please contact me at 423-832-5172. Please reference the unique document identification number in any correspondence concerning this letter.

Sincerely,

Richard D. Montgomery

Richard D. Montgomery, Advisory Engineer
Nuclear Criticality Safety & Shipping Containers

Cc:
J. Umaña, Project Manager
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards,
U.S. Nuclear Regulatory Commission,
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NMSS01

Attachment I

Consolidated License Application
Framatome ANP, Inc.,
Model DHTF Shipping Container

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AREVA

Document Identification No.
51-9010760-000

Consolidated License Application
Framatome ANP, Inc.,
Model DHTF Shipping Container

Revision 4
January 2006

Consolidated License Application

Framatome ANP, Inc.,

Model DHTF Shipping Container

Certificate of Compliance No: USA/9203/AF
Docket No: 71-9203

Record of Revisions

Revision 4 – 01-20-2006
Revision 3 – 10-29-99
Revision 2 – 09-10-96
Revision 1 – 05-31-96

Nature of Changes

Revision 4 – 01-20-2006

Item	Paragraph or Page(s)	Description and Justification
1.	Cover pages	Changed Framatome Cogema Fuels to Framatome ANP, Inc. Added FANP Document Identification Number 51-901076-000.
2.	i/ii/iii	Added record of revisions. Revised Table of Contents. Moved existing sections 2.8 and 2.9 to sections 2.9 and 2.10 with addition of new section 2.8 for inclusion of test results for D08 and D09 and further change pages. Deleted listing of tables in section 6.0 for consistency with other sections.
3.	1-1	Changed the transport index from 1.3 to 1.2 and Max. # Packages from 76 to 83 for consistency with prior submittal.
4.	1-5	Changed typo, UO^2 to UO_2.
5.	2-4	(a) changed 221 to 22 ½ (f) corrected typo (g) changed IOO to 100
6.	2-5	(a)(1) changed –dnd to and. (a)(2) added reference to section 2.8 2.6.1 changed IO to 10.
7.	2-6	2.6.1, added reference to section 2.8
8.	2-7	Reworded second sentence in 2.6.5. Changed DOI to D01, several instances.
9.	2-8	2.6.8, changed 141 to 1 ¼ and .23 to 0.23. 2.7, modified header to indicate test containers D02 through D07 Changed drum identification from DOX to D0X, as applicable.
10.	2-9	2.7, third paragraph, Changed 301 to 30'. 2.7.1, changed And to and, and deleted reference to photographs for tests D02 through D07 since they were omitted in the previous revision.
11.	2-10	2.7.2, changed 61 to 6', and temperature indicated as OF to °F.
12.	2-12 through 2-14	Incorporated section 2.8, Hypothetical Accident Conditions – Test Containers D08 and D09, which was provided in a prior submittal. Original page 2-12 became 2-15 with added pages.
13.	2-15	Renumber section 2.8 and 2.9 to 2.9 and 2.10. Incorporated Table 2.7 and Figure 2.11. Indicated that 21 pages of test photographs are attached.

14.	Table 2.5	Changed temperature from 17500F and 14750F to 1750°F and 1475°F.
15.	Table 2.6	Incorporated test data from section 2.8.3 for D08 and D09.
16.	Table 2.7 Figure 2.11	Incorporated table/figure and adjusted remaining table/figure page numbers.
17.	Pages 2-34 through 2-51	Incorporated test photographs on numbered pages as opposed to unnumbered inserts.
18.	7-1	Changed CNFP and FCF to FANP. Changed 10 CFR 20.205 to 10 CFR 20.1906.
19.	7.2.1 through 7.2.4	Added bullet to each, Pellet dimension within defined range. Arranged bullets for consistency between sections.
20.	7.2.2	Changed Al to Aluminum.
21.	7.2.8	Changed second bullet reference from inappropriate reference to 7.2.3 to correctly reference section 7.2.5 - 7.2.6.
22.	7.4.1	Incorporated prior changed, third bullet from eight bolts to secured in place.
23.	8.2.1	Added bullet to indicate that stainless steel plate is provided.
24.	8.2.2	Added requirement for dimensional check of stainless steel plate.
25.	8.3	Incorporated revised wording for gasket inspection and replacement for consistency with condition 9(a) of COC.
26.	9-11	Changed CNFP to FANP and copyright symbol © to note (c)

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1. GENERAL INFORMATION

1.1 Introduction

The DHTF package is a shipping container that has been designed, built and tested for use as a container for transport of fissile radioactive material in the form of uranium dioxide pellets. Table 1.2 defines terminology used in this license application to describe the DHTF package and its contents.

Transport indices and maximum allowable number of packages will be as follows:

Packing Method	
Corrugated Trays:	
Transport Index	1.2
Max. # Packages	83
Bagged Pellets:	
Transport Index	1.2
Max. # Packages	83

The complete and comprehensive series of test as outlined in 10 CFR 71 were performed on the DHTF between August 29, 1985 and September 20, 1985 to verify compliance with the requirement of 10 CFR 71. Additionally, since the DHTF will be used in foreign countries, we have also satisfied the appropriate requirements of Safety Series No. 6, IAEA Safety Standards, "Regulations of the Safe Transport of Radioactive Materials", 1973 Revised Edition (As Amended).

1.2 Package Description

1.2.1 Packaging

The overall package consists of a DOT Spec 17C or UN1A2/X400/S cylindrical outer drum (approximately 35 inches high, 22 ½ inches in diameter, and nominal 55 gallon capacity) with a stainless steel insert as containment for the cardboard pellet boxes. Filler material between the inner and outer containers consists of industrial can fiberboards disks which are cut to shape and stacked inside the outer drum. This forms the inner container cavity and yields sufficient mechanical strength and thermal resistance to protect the contents from damage during normal and hypothetical accident conditions of transport. Specification ASTM-C-208-72 sets forth requirements for several types of cellulosic insulating board; the DHTF uses filler material of the category "Roof Insulating Board, Construction Grade".

The stainless steel inner container uses a steel plate closure lit (3/8" thick) which is secured by eight 3/8-16 NC bolts. A 1/8" rubber gasket with a 500°F thermal rating is used between the inner container lid and body. The inner container is 9.5"x9.5"x17.5"

in size and is centered within the DOT 17C outer drum. More details can be found on Drawing No. 1249874.

The maximum gross weight of the DHTF will be 490 pounds when loaded with four cardboard boxes of uranium dioxide pellets; Table 1.1 provides details. Actual gross weight will vary from this for two reasons. First, density of the fiberboard filler material will vary. The fiberboard density will be controlled to a value of 16.5 $lbs/ft^3 \pm 2$ lbs/ft^3. Second, the DHTF may carry fewer than four cardboard boxes of pellets.

1.2.2 Operational Features

Operation of the DHTF container is typical of 55-gallon drums. The cylindrical drum is sealed with a 16-gauge top lid secured by a 12-gauge closure ring with a 5/8" bolt and nut through drop forged closure ring lugs. Loading of the DHTF is accomplished by placing the loaded pellet boxes and stainless steel centerboard inside a nylon strap as shown on Drawing 1249874. This entire payload can then be lowered into the DHTF inner container. Unloading of the container is accomplished in reverse fashion.

1.2.3 Contents of Package

The DHTF will carry a payload of up to four cardboard boxes of UO^2 pellets. Pellets are packed in one of two methods, either neatly stacked on corrugated stainless steel trays, or randomly placed into a polyethylene bag within the cardboard box. If pellets are packed on corrugated trays, the DHTF is limited to a total payload of 112 kgs UO^2 for nuclear safety purposes. For bagged solid pellets, the U^{235} shall not exceed 3.72 kgs & 3.55 kgs for annular pellets.

The maximum weight limit is 246.91 pounds (112 Kg) of UO_2 (4 boxes of fuel) with the U^{235} content not to exceed 4.83 kg U^{235} for the **pellet-tray** configuration. For the **scrap** configuration, the U^{235} content shall not exceed 3.72 kg U^{235}. For **scrap** annular fuel the content of U^{235} shall not exceed 3.55 kg. No annular fuel is allowed in the pellet-tray configuration.

If the content of the drum is limited to 185.18 pounds (84 kg) of UO_2 (3 boxes of fuel) with the remaining space of one box occupied by an aluminum spacer the U^{235} content shall not exceed 3.62 kg U^{235} (5.00 wt% U^{235}) for solid pellet fuel in the scrap configuration or 3.55 kg U^{235} (5.00 wt% U^{235}) for annular pellet fuel.

Uranium dioxide pellets have a maximum theoretical density of 10.96 gms per cubic centimeter. In practice, densities of 10.4 - 10.6 gms per cc are typically achieved. The DHTF will be used only for unirradiated pellets. As such, they do not generate heat, do not cause pressure buildup within the inner container, and do not require radiation shielding.

1.3 Appendix

- Table 1.1 - Normal Weights of DHTF Components
- Table 1.2 - Definitions and Terms
- Drawings 1249874, "DHTF Shipping Container Details and Assembly and 1215600, "Method Of Packaging UO2 Pellets" are included as part of this license application.

TABLE 1.1

NOMINAL WEIGHTS OF DHTF COMPONENTS

Outer Drum	-	60 lbs. (including ring, bolt, lid)
Fiberboard packing	-	105 lbs. (at 16.5 pounds per cubic foot)
Inner container	-	50 lbs. (including bolts, washers, nuts, gasket, lid)
SS centerboard	-	25 lbs.
Subtotal, nominal weight of DHTF Packaging		240 lbs.
Payload (gross wt.)		250 lbs. (including cardboard, plastic, tape, labels)
Total gross weight of DHTF Package		490 lbs.

TABLE 1.2

DEFINITIONS AND TERMS

Regulatory Definitions (Ref. 10 CFR 71.4)

"Containment System" means the components of the packaging intended to retain the radioactive material during transport. This is most commonly referred to as the inner container of the DHTF.

"Package" means the packaging together with its radioactive contents as presented for transport. (DHTF w/Payload).

"Packaging" means the assembly of components necessary to ensure compliance with the packaging requirements of 10 CFR 71 (DHTF w/o payload).

DHTF Components -- The DHTF consists of four primary components:

"Outer Drum" means the DOT 17C or UN1A2/X400/S drum that contains all other components of the DHTF package.

"Inner Container" means the Containment System of the DHTF Package.

"Fiberboard" means the industrial cane fiberboard filler material used to center the inner container within the outer drum; Part #3 of Drawing 1249874.

"Payload" means the assembly of nuclear fuel in cardboard boxes, strapped to ½-inch spacer, and transported within the Inner Container.

Alternate Language

"Contents" means Payload.

"Filler" or "Filler Material" means Fiberboard.

"Shipping Container" means Packaging.

"Packing Material" means Fiberboard.

Pellet Packing Methods

"Pellets on corrugated trays" means the packing method used for product pellets wherein pellets are neatly aligned in columns on corrugated stainless steel trays.

"Bagged pellets" means the packaging method used for scrap pellets wherein pellets are randomly dumped into a polyethylene bag. (Chipping and other aspects of pellet quality are not of concern.).

"Alternate Pellet Packaging Method" means Pellets on Corrugated Trays.

"Random Packing of Pellets" means Bagged Pellets.

"Bagged UO_2" means Bagged Pellets.

2. STRUCTURAL EVALUATION

This chapter presents the structural evaluations demonstrating that the design of the DHTF shipping container meets all applicable structural criteria to ensure safe, reliable shipment of its radioactive contents. Normal operation and hypothetical accident conditions are addressed by analytical and experimental evaluations performed in accordance with the requirements of 10 CFR 71.71, 71.73, and the IAEA regulations (709-714 and 719-721). Extensive full-scale testing of prototype shipping containers was performed to verify that the behavior of the package under all conditions was within the limits assumed in the criticality analysts.

A summary of the structural design of the DHTF container is presented in Section 2.1. including the design criteria used to evaluate the packaging performance. Section 2.2. is a listing of the weights of the packaging and contents. Materials of construction are presented in Section 2.3. The prototype test program is discussed in Section 2.4. Results from the evaluations that demonstrate compliance with the design criteria for general standards for all packages, normal conditions of transport, and hypothetical accident conditions are presented in Sections 2.5. thru 2.7.

2.1. Structural Design

2.1.1 Discussion

Structurally, the DHTF shipping container (Drawing No 1249874) consists of an inner container supported within a protective outer shell by a filler material. The inner container functions as the containment boundary for the package contents, In the criticality analysis, the array spacing for stacked packages is governed by the geometry of the outer shell and packing material.

2.1.1.1 Outer Drum (Part No. 2 of Drawing 1249874)

A standard commercial product, the DOT Spec 55-gallon or UN1A2/X400/S drum utilized as the outer shell of the DHTF shipping container has a history of successful in-service use in similar applications. In this application, it functions as a structural shell and an environmental barrier as well as maintaining geometric control for the array of packages used in the criticality analysis. Its outer diameter determines how close the containers can be to each other in computing the nuclear interaction between the packages within an array. Structurally the drum provides an outer shell capable of absorbing and redistributing external loading resulting from handling, operation, and accidental impacts with other structures. Vent holes in the drum preclude a buildup of a differential pressure across its wall. There are no attachments for lifting or tie-down devices.

2.1.1.2 Inner Container (Part No. 5 of Drawing 1249874)

Centered within the drum, the inner container (comprised of a welded body with a removable top cover) functions as the containment system. Two 14-gage stainless steel angle sections are welded together longitudinally to form a vessel with a square cross-section. Its 1/4-inch-thick bottom closure plate is attached with a full perimeter weld. An-external flange fabricated of 1-1/2-inch steel angle is attached at the top of the vessel body to accommodate the bolted closure plate. Eight 3/8" bolts secure the cover to the body while compressing the full cross-section silicon rubber gasket to seal the vessel. A gasket thickness of 1/8 inch permits sufficient compression of the rubber to produce a forgiving seal design that is not impaired by minor surface imperfections on the mating metal surfaces. With a temperature rating of 5OO F, the gasket is relatively unaffected by the temperature changes resulting from severe temperature transients such as the fire accident. The removable cover is a 3/8-inch steel plate.

2.1.1.3 Fiberboard Packing (Part Numbers 3-1 and 3-2 of Drawing 1249874)

Circular disks (drum I.D.) with a square cut-out where required for the inner container, the fiberboard packing completely fills the void between the outer drum and inner container. Its resilient properties absorb the impact energy from the inner container during the drop impact loading. While experiencing minor deformation itself in local areas, the packing prevents any significant displacement of the inner container relative to the outer drum. As a thermal insulator, it moderates the heat transfer between the outer environment and the inner container and its silicon rubber gasket.

2.1.2 Design Criteria

A straightforward licensing approach utilizing an extensive prototype testing program was selected for the DHTF container. This approach to the structural evaluation permits a direct measurement and assessment of the safety and reliability capabilities inherent in the container design.

Design requirements for normal conditions of transport and hypothetical accident conditions as presented in the regulations, IOCFR71 and IAEA, are listed in Table 2.1. Where there is an inconsistency between the regulations, the more severe requirement was used. These requirements were transformed into specific design criteria, Table 2.2, that could be evaluated directly from prototype test results and analytical evaluations.

2.2 Weights and Center of Gravity

Loaded for shipment, the DHTF shipping container has a nominal weight of 490 pounds. This includes a maximum payload of 250 1-bs. of uranium oxide pellets. A listing of component weights is presented in Table 1.1.

Nearly symmetrical, the center of gravity of the container is very near its geometric center -- mid-height on drum centerline.

2.3 Materials of Construction

Standard commercial materials (304 Stainless Steel, carbon steel, and industrial cane fiberboard) are used in the construction of the DHTF shipping container. A listing of the materials an specifications is presented in Table 2.3 and on the license drawing 1249874.

2.4 Prototype Test Program

2.4.1 Prototype Canisters

Prototype containers used for the testing program were representative of the production containers: materials of construction, fabrication techniques, and loading procedures were identical. Component procurement, fabrication, and inspection, and prototype assembly and inspection, were conducted in accordance with the requirements of B&W's approved "Shipping Container Quality Assurance Program" dated 12-14-84.

Of relatively compact and straightforward design, the behavior of the inner container is directly related to the weight/mass of its contents and the impact "g" loading. Actual container payloads will be comprised of up to four (4) cardboard boxes of unirradiated fuel pellets and a stainless steel plate divider. To simulate the radioactive contents for the prototype, each of four cardboard boxes (identical to those used to package actual fuel pellets) was loaded with two lead bricks (29 lbs. each) separated by a small bag of sand. The boxes were taped closed and stacked together two high, separated by *a* 112- inch steel plate. A nylon strap bounds the four boxes and steel plate together for loading into the inner container of the DHTF package. The combined weight of the contents (four boxes and steel plate) was 280 lbs. This loaded arrangement closely duplicated the actual case wherein the maximum shipping weight is 250 lbs. of uranium oxide plus a 20 pound steel plate.

2.4.2 Loading Configurations

In the cases where the loading configuration is to produce "maximum" damage, the test requirements were reviewed with respect to the structural configuration of the DHTF container. Drop tests, in particular, are sensitive to the container's internal structural stiffness at the point of impact. For operational considerations, a square inner container was incorporated into the DHTF container design. Fiberboard packing supports the inner

container within the outer drum. This square-within-a-circle configuration does not lend itself to a single "worst case" test. To ensure the testing program addressed all possible orientations where maximum damage could occur, with a multiple drop sequence or sing drops of a set of prototype containers was incorporated into the test program.

2.5 General Package Standards

2.5.1 General Standards for all Packages

General standards for all packages are as specified in 10 CFR 71.43:

(a) Smallest overall dimension of the DHTF is its diameter (22 ½ inches).

(b) The DHTF will be sealed with a Type E metal tamper seal applied to the clamping ring bolt.

(c) The inner container is securely closed by eight 3/8-inch bolts that cannot be unintentionally opened.

(d) Materials of construction (carbon steel, stainless steel, cane fiberboard, and silicon rubber) will exhibit no significant chemical, galvanic, or other reaction among the packaging components or between the packaging components and the package contents.

(e) The DHTF has no pressure relief devices, valves, or other devices the failure of which would allow radioactive contents to escape.

(f) As discussed in Section 2.6 below, the DHTF passed all Normal Conditions tests with no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.

(g) Unirradiated uranium oxide pellets shipped in the DHTF container do not generate heat. Therefore, no unusual temperature buildup can occur, and the surface temperature of the package will not exceed 122°F if the package is placed in still air and in the shade at 100°F.

(h) A sealed containment, the DHTF shipping container does not permit venting of radioactive content during transport.

2.5.2 Standards for Type B Packages

Additional requirements for Type B packages are as specified in 10 CFR 71.51:

(a) (1) As discussed in Section 2.6 below, the DHTF passed all Normal Conditions tests with no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.

(a) (2) As discussed in Sections 2.7 and 2.8 below, the DHTF passed all Hypothetical Accident Conditions tests with no escape of radioactive material and not external radiation dose rate exceeding one rem per hour at one meter from the external surface of the package.

(b) The DHTF package uses no filters and has no mechanical cooling system.

2.5.3 Standards for Fissile Material Packages:

Requirements for fissile material packages are as specified in 10 CFR 71.55:

(a) As discussed above, The DHTF is designed and constructed in accordance with 10 CFR 71.41 through 71.51.

(b) A single DHTF is subcritical if water were to leak into the containment system under conditions of maximum reactivity of the fissile material.

(c) As discussed in Section 2.6 below, the DHTF package passed all Normal Conditions tests by meeting or exceeding the criteria appearing in 10 CFR 71.55(d)(1) through (d)(4).

(d) A 28x3 DHTF array, in a damaged condition following Hypothetical Accident Conditions tests, is subcritical under the most reactive credible conditions for geometry of the contents and water in leakage, moderation, and reflection.

2.5.4 Standards for Arrays of Fissile Material Packages:

Chapter 6 of this license application demonstrates that the DHTF package meets the requirements for 10 CFR 71.59 for Fissile packages.

2.6 Normal Conditions of Transport

2.6.1 Heat

For the heat test for normal condition of transport per IAEA regulations, the package is to be subject to an ambient temperature of 70°C (158°F) in still air which bounds the requirements of 10CFR71 for a 38°C (100°F) temperature. This test would result in only a modest increase in the temperature of the drum exposed to the heat input and to the inner container that is shielded by the thermal insulation properties of the fiberboard spacers. No internal heat is generated by the uranium oxide contents in the inner container.

No significant temperature gradients exist in the DHTF package as a result of the heat conditions. The large surface area and thin wall construction of the drum precludes any build-up of a temperature gradient and associated differential expansion stresses that could affect the integrity of the outer shell.

Moderated by the insulation properties of the fiberboard, the inner container does not experience any significant temperature transients. Differential expansion between the stainless steel body and carbon steel cover and flange is negligible.

Silicon rubber with a temperature rating of 500°F is used for the inner container gasket material. No deterioration of the gasket is expected during normal transport. In fact, no significant deterioration of the gasket was observed as a result of the much more severe fire accident (Sections 2.7 and 2.8).

2.6.2 Cold

The inner container body is fabricated from type 304 stainless steel. Since this material does not undergo a ductile-to-brittle transition in the temperature range of interest (down to -40°F), it is safe from brittle fracture.

2.6.3 Pressure

As stated in the regulations, the package must be evaluated as to the effect of subjecting the container to a reduced external pressure of 3.5 psi absolute and an increased external pressure of 20.0 psi absolute. These values translate into a bursting pressure of 11.2psig and a crushing pressure of 5.3 psig, respectively. For the DHTF container, the drum is vented and the fiberboard offers no pressure resistance. The inner container, functioning as the seal containment boundary, is the only structural component effected by a pressure differential.

As part of the prototype testing program, the inner container of Drum #D01 was subjected to a bursting pressure of 14 psig (vs. 11.2 psig required) for a period of one hour with no reduction noted over the test interval. A schematic of the pressure test apparatus is shown in Figure 2.1. The same inner container was also subjected to an internal vacuum of 20 inches Hg that translated to a 9.8 psig crushing pressure (vs. 5.3 psig required). Monitored at 15-minute intervals, no pressure change was noted during this test, either. See Table 2.4.

Results from the prototype testing have demonstrated that the DHTF container meets or exceeds its design criteria of maintaining a pressure-tight seal in the range of external pressure from 3.5 psia to 20.0 psia. This also verifies that no water in leakage is expected for normal conditions of transport.

2.6.4 Vibration

The effects of vibration normally associated with transport conditions are considered to be negligible with respect to the DHTF container. The conclusion is based on the compact nature of the container design and the damping action of the fiberboard packing. Any induced stress would be of very small magnitude and would not be detrimental to the normal operation of the package. Both the drum and fiberboard packing are standard commercial products with a long history of successful in-service operation.

2.6.5 Water Spray

Due to the nature of the material utilized in the outer drum (steel), the water spray test requirement have no effect on the DHTF package. This was demonstrated as part of the prototype test program, again using Drum #D01 (Figure 2.2). A water flow test of 1.16 gallons/minute (equivalent to approximately 15 inches/hour of rainfall) was used. No water in leakage was observed inside Drum #D01 after being subjected to the water spray test.

The water spray test was used as a pre-conditioner of the prototype package used in the drip, compression and penetration tests.

2.6.6 Free Drop

Normal operation free drop requirements of 10 CFR 71(c)(7) have a negligible effect on the overall structural performance of the DHTF package. Some local deformation at the points of impact were observed. This type of minor deformation of the outer drum is not detrimental to integrity of the container and is not significant with regards to the criticality analysis.

After being conditioned by a water spray test, the prototype container #D01 was subjected to a series of one-foot drop test onto a horizontal unyielding surface on each quarter o the drum container rims as required for cylindrical fissile class II packages a sown in Figure 2.3. Only minor deformation of the rims was observed. At the completion of the series of on-foot drop test, Prototype #D01 was then dropped from a height of four-feet onto an unyielding surface. A total of six 4' drop tests were performed using the various orientations shown in Figure 2.4. The slight deformations of the outer container and closure ring did not impair the structural integrity of the package and were within the limits assumed in the criticality analysis.

2.6.7 Compression

Due to structural capabilities of the drum, the compression test as specified in the regulations has a negligible effect on the performance of the DHTF container. Prototype testing demonstrated that for staking the containers in a vertical position, the required loading has no measurable affect on the canister. A load of 2930 pounds was twice

applied axially to Drum D01 for periods of more than 24 hours. This loading exceeded the required loading of the greater of 5 times the loaded container's weight (5x480=2400 pounds) or 1.85 psi times the projected area of the package (830 pounds). No damage occurred due to compression loading.

2.6.8 Penetration

The penetrations test specified as part of the normal conditions of transport do not have a significant effect on the effectiveness of the DHTF container due to the strength of the outer drum. During testing of Drum D01 (Figure 2.5), a vertical steel cylinder 1 ¼ inches in diameter with a hemispherical end was dropped form a 40" height onto the most vulnerable portions of the container. This was the last of the Normal Conditions tests; the prototype container had already been subjected to the water spray, free drops and compressions tests. The 13 ¾ pound cylinder was dropped on the lid, on the bottom, and on the side of the drum. It did not penetrate the outer skin, and the maximum local depression was 0.23 inches (on side of drum).

All damage was within the limits assumed in the criticality analysis. The damage from the penetration test is shown in the photographs.

2.6.9 Summary of Damage

After completion of the structural testing program, the prototype container (#D01) was subjected to a comprehensive post-test inspection. Dimensional checks verified that the inner container was not deformed and remained well within the limits imposed by the criticality analysis. Local deformations of the drum at the points of impact are not significant in terms of changes to the criticality analysis. After repeated drop loads, some minor crushing of the fiberboard spacers was noted. These values translate into an insignificant shifting of inner container relative to the outer drum (les than a 5% change). The criticality analysis bounds all postulated configurations.

2.7 Hypothetical Accident Conditions – Test Containers D02 through D07

Evaluation of the DHTF package for the hypothetical accident conditions described in the regulations required a series of tests performed in a given sequence. Package performance was then assessed based on the accumulated damage. An exception of this procedure is the 50-foot water immersion test where an undamaged container was used as required by 10 CFR 71.73 (c)(5).

Prototype containers used for the testing program were representative of the production containers as discussed in Section 2.4.1. This includes material of construction, fabrication techniques and loading procedures. The combined weight of the contents (four boxes and steel plate) for the prototype containers was 280 pounds. For actual shipments, the maximum shipping weight will be 100 kgs uranium plus a steel plate for a combined weight of approximately 275 pounds.

To ensure the testing program addressed al possible impact configurations where "maximum" damage was expected, a set of six containers were drop-tested. All the containers were subjected to a 30 foot drop in one of six orientations likely to cause maximum damage. Figure 2.6 illustrates all six orientations used for the 30' drop tests including closure bolt location, inner container location, and overall drum attitude. Each container was then subjected to a series of four puncture tests (Figure 2.7). But the end of these two mechanical tests, each of the six containers (D02 through D07) had experienced five drop/puncture tests. Next, the entire set of six drums was placed in a furnace for the thermal test. A post-test examination was performed on all six containers at the conclusion of the test series. Using this approach, a broad data base of experience was accumulated on the performance of the DHTF container.

2.7.1 Free Drop

Six prototype DHTF containers (Numbers D02 through D07) were subjected to a drop test onto an unyielding surface to demonstrate their structural performance at various impact configurations. The containers were positioned 30 feet above the drop pad (Figure 2.8) at a different angular orientation and released. The orientations were selected to potentially produce the greatest damage to the package upon impact.

Each container was dropped once and then visually inspected for damage to the outer drum. Since the accident tests are done in series and the final assessment is based on the accumulative damage, the package was not disassembled until all the accident tests were completed. Results of the post-drop test examination were to verify no gross failure of the drum had occurred such as the lid coming off.

2.7.2 Puncture

After completion of the free drop tests, each of the six containers (D02 through D07) were subjected to a series of four puncture tests as shown in Figure 2.7. The packages were dropped through a distance of 40 inches, impacting the top end of a vertical steel cylinder rigidly mounted on the drop pad, a horizontal, unyielding surface. The bar was six inches in diameter and 30 inches long which assured a full impact in the configurations shown in Figure 2.7 before contact with the ground.

A visual inspection of the outer drum showed only minor local deformations had occurred. The lid and clamping ring remained in place for all tests. No breach of the drum was observed.

2.7.3 Thermal Test

Each having passed a single 30-foot drop and four 40-inch puncture tests, drums D02 through D07 were next subjected to a thermal test. The test took place in Reidsville, North Carolina in the largest furnace owned by Carolina Heat Treaters, Inc. The furnace, 15'x4'x6' high, was hinged at the bottom back and opened much like a yawning mouth. Two temperature control circuits operated the electric heating elements.

The furnace was preheated to 1750°F and then loaded. Drum Nos. D03, D04 and D07 occupied control Zone #1; Drums D02, D05 and D06 were placed in Zone #2. Temperatures in both zones naturally plummeted during the loading operation, falling to a low of about 1300°F seven minutes after the furnace had been opened. Zone #2 then achieved a 1475°F at t=15 minutes. An electrical short, probably due to contact between the drums and the heating elements, prevented Zone #1 from achieving desired temperature; it stabilized at 1270°F instead.

An attempt was made to remove the drums at t=45 minutes (i.e., 30 minutes after Zone #2 had returned to 1475°F). Flames issued forth as soon as the furnace was opened, however, leaving no choice but to close the furnace again. The drums remained inside until the furnace cooled enough to permit the drums to be safely removed. In all, the drums were exposed to excessive temperatures fro 17 hours, a far more rigorous test than initially planned. (Furnace temperature at t=17 hours was still 230°F). Table 2.5 presents time vs. temperature data of the test; Figure 2.9 depicts this relationship graphically.

Since the thermal test was the last of the accident conditions tests, all six drums were dismembered and thoroughly inspected, both visually and dimensionally. The following observations were true for all drums:

- The topmost fiberboard disk had charred nearly to ash.
- All disks had charred uniformly about their circumference, resulting in slightly smaller disks. On the average, disk diameter range from 22.1" to 21.4". Table 2.6 gives information for all drums.
- Charring was confined to the edges of the fiberboard disks, as the center portions evidenced no discoloration.
- Upper disks charred more than lower disks.
- Inner container gaskets were undamaged.
- Inner containers were undamaged.
- The cardboard pellet boxes did not burn.
- The poly linters melted.
- Lead bricks were not affected.

The charring pattern obviously followed a temperature/oxygen patter. Charring was most severe where both heat and air were present, as exhibited by the sever charring of the topmost disks (close to vent holes; close to the hot surface temperatures of the drum lid). Charring was limited where heat was present but airflow restricted, as exhibited

by the limited charring of outer circumferences of the fiberboard disks. Charring was absent where heat was absent, as at the center of the fiberboard disks. The thermal test and post-test inspections can be seen in the photographs.

2.7.4 Water Immersion - Fissile Packages

Completion of the thermal test marked the end of the accident testing for Drum Nos. D02 through D07. Water in leakage has been assumed in the criticality analysis for the accident cases; the three-foot immersion test [10 CFR 71.73(4)] is thus not required in the sequence of tests.

2.7.5 Water Immersion - All Packages

An undamaged DHTF container was used for the 50-foot water immersion test. The container was submerged in Smith Mountain Lake near the Babcock & Wilcox facilities. Additional weight was attached to the container to insure it would sink to the 50-foot level where it remained for more than eight hours in a horizontal orientation. The container was retrieved and transported back to Babcock & Wilcox in an upright position for a post-test examination.

Visual inspection of the drum as it was being disassembled revealed no structural damage to any component. Moderate water leakage into the volume between the outer drum and inner container resulted in saturation the lower fiberboard disc. There was no water in leakage into the inner container.

2.7.6 Summary of Damage

From the prototype test program, a broad data base was obtained on the behavior of the DHTF shipping container during accidents. Package performance was assessed based on the accumulated damage from the 30-foot drop/puncture/ thermal test sequence. An undamaged container was used in the 50-foot immersion test.

Deformation patterns of the set of six drums used in the drop/puncture/ thermal tests varied as shown in the photographs. While deformations of individual containers varied, their overall performance was very similar. All drums remained intact with their lids attached. Some charring of the fiberboard was observed, but immediately adjacent to the inner container, the fiberboard remained undamaged during the thermal test. In all cases, the inner vessel was undeformed and the gasket intact.

A visual inspection of the package after the 50-foot immersion test verified that no damage had occurred to the inner container and gasket. The drum remained undamaged with its lid attached.

As demonstrated by the prototype testing, the DHTF shipping container meets its design criteria for hypothetical accident conditions.

2.8 Hypothetical Accident Conditions – Test Containers D08 and D09

Subsequent to the testing of prototype shipping containers D02 through D07 (Section 2.7), two additional prototypes were subjected to the drop/puncture/thermal sequence required by 10 CFR 71.73 (c)(1), (c)(2) ad (c)(3). Only the thermal test differed. An open-air burn of gasoline was used instead of an electric heat treating furnace.

Prototypes were representative of production containers as discussed in Section 2.4.1. Each container was dropped thirty feet onto its closure bolt. The attitude of each container for the thirty-foot drop test was such that the center of gravity of the container was perpendicular to the four puncture tests after completion of the 30-foot drop test. Following the open-air burn, the prototypes underwent a thorough examination to evaluate accumulated damage.

2.8.1 Free Drop

The thirty foot drops for Drums D08 and D09 are shown in Photographs 81-1 through 82.3. No gross failure of the drums occurred. The damage incurred on Drums D08 and D09 is virtually the same as seen on Drum D02.

2.8.2 40" Puncture

After completion of the free drop tests, both D08 and D09 were subjected to four puncture tests as shown in Figure 2.7. No breaches of the outer drum resulted. The damage to D08 and D09 from the four 40" puncture tests is almost identical to that seen on Drums D02 through D07.

2.8.3 Thermal

Each having passed a single 30-foot drop and four 40-inchg puncture tests, (see Sect. 2.8.1, 2.8.2) prototypes D08 and D09 were next subjected to an open-air burn of gasoline. Figure 2.11 shows the test setup. Two trial burn tests established required flow rates for gasoline (~ 5 GPM) and water (~ 2 GPM) as well as the need for a small windbreak around the burn pan. Prototypes, burned one at a time, were positioned horizontally about three feet above the center of the burn pan. The pan was sized (8' x 6') to permit a wall of lame approximately 2-3 feet thick on all sides of the prototype.

Temperatures were measured via thermocouples placed at mid height on each of the four sides of the test containers. Each of the thermocouples were attached to the structural support, within six inches of the outer surface of the prototypes. Additionally, tow optical pyrometers were used to measure flame temperature.

The first thermal test was performed on Drum 09. Drum 09 was placed in the test fixture and gasoline was allowed to accumulate on top of the water and then ignited. The temperature rise was rapid and the drum remained engulfed in flames throughout the testing. The wind wall that was erected during the trial burn test was extended to cover essentially two sides of the test fixture. This helped to negate the effects of wind currents and keep the drums covered by flames during testing. The same procedure and setup was used from Drum D08.

The sequence of events was identical for both burns. A few minutes into the testing, steam could be seen coming out of the four vent holes at the top of Drum D08 and D09 due to heading of the fiberboard packing material. Simultaneously, the pressure inside the drums rapidly increased. The steam coming out of the vent holes soon changed to flames due to elevating temperatures inside the drums. Flames could also be seen at times coming from between each drum lid and closure ring as a result of the outer lid gasket being burned away. Both drums remained in the fire past the 30 minute regulatory requirement. The four thermocouples used to monitor temperature indicated average values in excess of 1500°F over the duration of the test. Additionally, the two optical pyrometers consistently indicated flame temperature from 2000-2100°F during the tests.

After completion of the testing, the drums were removed from the test fixture and set aside to cool naturally. Each drum was then completely taken apart and thoroughly inspected both visually and dimensionally. The following observations were true for both drums.

- The top and bottom fiberboard disks were extensively charred.
- All disks were uniformly charred around their circumference which resulted in a decrease in overall disk diameter. On the average, disk diameter shrank from 22.1" to 21.5" for Drum D08 and from 22.2" to 21.5" for Drum D09 (see table 2.6).
- Charring was confined to the edges of the fiberboard disks.

- Inner container gaskets were complete undamaged.
- Temperature crayons in the inner container all indicated less than 150°F.
- All Contents (plastic bags, lead bricks, cardboard boxes, nylon straps, etc.) were undamaged form the thermal test and completely contained within the inner container.

2.8.4 Comparison

The open air burn test performed on Drums D08 and D09 was less severe than the oven burn test performed on Drums D02 through D07. This is based on the following observations:

- The overall duration for the oven test was ~ 17 hours whereas the open air burn lasted for only approximately 35 minutes.
- The nylon strap was partially melted, and plastic bags completely melted, in Drums D02 through D07. Nylon and plastic were completely intact in Drums D08 and D09.
- The fiberboard charring seen in Drums D02 through D07 was more sever than that seen in D08 or D09.

FIGURE WITHHELD UNDER 10 CFR 2.390

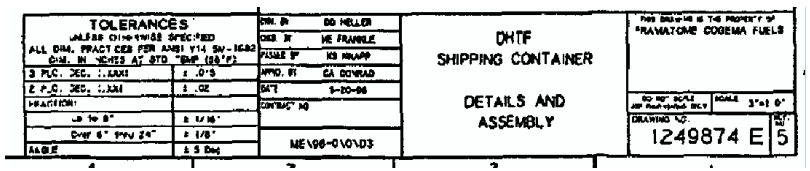

FIGURE WITHHELD UNDER 10 CFR 2.390

TOLERANCES			
UNLESS OTHERWISE SPECIFIED			
FRACTION:	UP TO 6"	±1/16	
	OVER 6" THRU 24"	±1/8	
	OVER 24"	±1/4	
DECIMAL:	2-PLACES - .XX	±.02	
	3-PLACES - .XXX	±.005	
ANGLE:	±1°		
ANGULAR DIM. FOR CHAM. & C'SINKS 5°			
FILLET RADII .03 R MAX.			
BREAK CORNERS .02 MAX. R OR CHAM.			
ALL MACHINED SURFACES 125/AA FINISH			

DWN. BY	DA BARGER
CHKD. BY	M. LAWRENCE
PASSED BY	D.F. ELLIOTT
APPVD. BY	
DATE	08-14-96
CONTRACT NO.	
	FS\91-7\2\D15

DHTF
SOLID PELLET BOX
SPACER

THIS DRAWING IS THE PROPERTY OF
FRAMATOME COGEMA FUELS

DO NOT SCALE
USE DIMENSIONS ONLY

SCALE 1:1

DRAWING NO. 1259100 C

REV. NO. 0

FIGURE WITHHELD UNDER 10 CFR 2.390

TOLERANCES UNLESS OTHERWISE SPECIFIED			METHOD OF PACKAGING UO2 FUEL PELLETS	THIS DRAWING IS THE PROPERTY OF FRAMATOME COGEMA FUELS
FRACTION: UP TO 6" ±1/16 OVER 6" THRU 24" ±1/8 OVER 24" ±1/4 DECIMAL: 2-PLACES - .XX ±.02 3-PLACES - .XXX ±.005 ANGLE: ±1° ANGULAR DIM. FOR CHAM. & C'SINKS 5° FILLET RADII .05 R MAX. BREAK CORNERS .02 MAX. R OR CHAM. ALL MACHINED SURFACES 125/AA FINISH	DWN BY R.W.GOOCH CHKD. BY AR SHUMAKER PASSED BY CG GIDEON APPD BY KS LESTER DATE 06\05\92 CONTRACT NO. FS/91-7/2/D11R6			DO NOT SCALE USE DIMENSIONS ONLY SCALE NONE DRAWING NO. 1215600 D REV. NO. 6

3 2 1

FIGURE WITHHELD UNDER 10 CFR 2.390

TOLERANCES					
FRACTION:	UP TO 6"	±1/64	DWN. BY DA BARGER	PELLET SHIPPING TRAY LICENSING	THIS DRAWING IS THE PROPERTY OF FRAMATOME COGEMA FUELS
	OVER 6" THRU 24"	±1/32	CHKD. BY		
	OVER 24"	±1/16	PASSED BY		
DECIMAL:	2-PLACES - .XX	±.02	APPVD. BY		
	3-PLACES - .XXX	±.005	DATE 08-16-96		DO NOT SCALE USE DIMENSIONS ONLY / SCALE 2:1
ANGLE:	±1°		CONTRACT NO.		DRAWING NO. 1259101 C / REV. NO. 0
ANGULAR DIM. FOR CHAM. & C'SINKS 5°			FS/91-7/2/D16		
FILLET RADII .03 R MAX.					
BREAK CORNERS .02 MAX. R OR CHAM.					
ALL MACHINED SURFACES 125/AA FINISH					

2 1 1

2.9 Tables and Figures

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Table 2.6	-	Fiberboard Disk Diameters Before and After Accident Conditions Testing
Table 2.7		Fiberboard Heat Tests
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Figure 2.11		Schematic of Open Air Burn Setup (Drums D08 and D09)

2.10 Appendix – Test Photographs

21 Pages

TABLE 2. 1 - Regulation Requirements For Package Testing

	Reference	
	10CFR71	IAEA
Normal Conditions		
• No loss or dispersal of contents	43(f)	225(a)
• No increase in external radiation levels	43(f)	225(b) 617-618
• Contents would be subcritical	55(d)(1)	615(c)
• Geometric form of contents not substantially altered	55(d)(4)(i)	615(c)
• < 5% reduction in effective volume of packaging	55(d)(4)(i)	615(a)
• < 5% reduction in spacing	55(d)(4)(ii)	615(a)
• No hole in drum large enough to pass a 10 cm cube	55(d)(4)(iii)	615(a)
• No water in leakage for criticality array		
Accident Conditions		
• Single package subcritical (damaged)	55(e)	--
• Single package subcritical (Damaged + in leakage)	--	617-618
• 2X subcritical (damaged + in leakage)	59(a)(2)	619(b)

TABLE 2.2 - Design Criteria - Structural

Normal Conditions of Transport

- No significant deterioration of the effectiveness of the package due to heat (158°F) and cold (-40°F)
- No susceptibility to brittle fracture at cold conditions (-40°F)
- Inner container to maintain pressure tight seal for external pressures from 3.5 psia (11.2 psid bursting) and 20.0 psia (5.3 psid crushing)
- Insensitive to vibrational environment
- Maintain geometric form of contents (< 5% reduction of volume of inner container)
- Positive closure devices for inner container
- Maintain geometric form of inner container as a containment barrier (no loss of contents) and effectiveness of its gasket (no water in leakage for array case)
- ≤ 5% reduction in effective width of fiberboard packing
- No opening in drum large enough to pass a 10 cm cube
- Outer drum effective diameter of 21.1 inches for array spacing
- Lid remains on drum under all loadings
- No continuous venting of radioactive contents during transport

Hypothetical Accident Conditions

- Effective drum diameter greater than 21.1 inches for array spacing controls
- Diameter of fiberboard disc greater than 21.1 inches for array spacing control
- Lid remains on drum
- Inner container with cover remains intact

TABLE 2.3 - Materials of Construction

Component	Material	Specification
55 gal Drum	Carbon Steel (16 Gauge)	DOT 17C 55 gal drum or UN1A2/X400/S
Drum - Lid	Carbon Steel (16 Gauge)	
Drum - Clamp Ring	Carbon Steel (12 Gauge)	
Drum - Clamp Ring Hardware	Carbon Steel - 5/8" bolt drop forged with 5/8 threads in lug	
Drum - Bolt Lug		
Fiber Board Spacers	Industrial Cane Fiber Board as defined in listed ASTM Spec	ASTM Spec C208-72 & C209-72
Inner Container Body - Weld Wire	304 SS	14 Ga. Sheet
Inner Container - Lid	Steel	3/8" Plate
Inner Container - Bolts/Nuts - Washers	Steel	3/8"-16 NC x 1 ½ Lg Zn Plated
Inner Container - Gasket	1/8" Silicon Rubber	40-60 Durometer 700 Tensile, 20 R compression 225 elongation 500OF rating

TABLE 2.4 - Pressure Tests Results

Test: Reduced External Pressure Test[a]

Pressure Differential (psig)	Time (Min.)
14	0
14	15
14	30
14	45
14	60

Test: Increased External Pressure Test [b]

Pressure Differential	Time (Min.)
20 in. Hg (9.8 psig)	0
20 in. Hg (9.8 psig)	15
20 in. Hg (9.8 psig)	30
20 in. Hg (9.8 psig)	45
20 in. Hg (9.8 psig)	60

NOTES:

(a) The test for reduced external pressure was simulated by pressurizing the inner container to 14 psig.

(b) The test for increased external pressure was simulated by drawing a vacuum of 20" Hg on the inner container.

Table 2.5

**Time and Temperature Data
for
DHTF Thermal Test of 4 Sept 85**

Elapsed Time (minutes)	Temperature (°F) Zone #1	Temperature (°F) Zone #2	Elapsed Time (Hours)	Temperature (°F)
0	1750	1750	1	1230
7	1300	1320	2	1020
15	1380	1480	3	895
22	1270	1460	4	795
30	1270	1460	5	710
35	1270	1460	6	635
40	1270	1460	7	570
45	1270	1460	8	515
50	1250	1360	9	470
60	1230	1230	10	430
			11	390
			12	365
			13	320
			14	295
			15	270
			16	250
			17	230

NOTES:

(a) Furnace preheated to 1750°F, then allowed to reheat to 1475°F before timing the start of the test.

(b) Furnace elements turned off at t = 45 minutes.

(c) Both zones at same temperature from t = 1 hour to t = 17 hours

Table 2.6

Fiberboard Disk Diameters Before and After Accident Conditions Testing

ELECTRIC FURNACE TEST (Section 2.7.3)					
		After (c)			
DRUM	Before (b)	Avg.	Min.	Max	Avg. Shrinkage
D02	22.20	21.30	21.06 (d)	21.63	0.90
D03	22.12	21.34	21.19	21.63	0.78
D04	22.14	21.56	21.5	21.88	0.58
D05	22.13	21.49	21.25	21.75	0.64
D06	22.19	21.63	21.5	22.0	0.56
D07	22.12	21.42	21.45	21.63	0.70
AVG.	22.15	21.46			0.69
OPEN AIR TEST (Section 2.8.3)					
D08	22.13 (e)	21.55	21.25	21.81	0.58
D09	22.17 (e)	21.50	21.13	22.13	0.67
Avg.	22.15	21.53			0.63

Notes:

(a) All figures are in inches.

(b) Average of four measurements per drum (2 disks @ 2 each).

(c) Sixteen measurements per drum (8disks @2 each) for Drums D02 through D07. 34 per drum for Drums D08 and D09.

(d) Only 1 of 16 measurements of D02 was below 21.1 inches.

(e) Average of 34

Table 2.7

Fiberboard Heat Tests

Elapsed Time (Hours)	Weight Loss		
	100°F	160°F	160°F (a)
6	2.2	6.7	2.7
24			5.9
48			7.1
72	3.8	7.3	7.7
96	3.8	7.3	7.7
120	3.5	7.1	
144	3.6	7.2	
168	3.5	7.2	8.4
192			8.4

Notes:

(a) Tested in a metal can with vent holes; other samples were simply exposed to air.

(b) A control sample was monitored at room temperature. It experienced no significant weight change.

(c) ASTM C-208-72 specifies a maximum moisture content of 10% by weight.

(d) No visible changes (e.g., charring or discoloration)

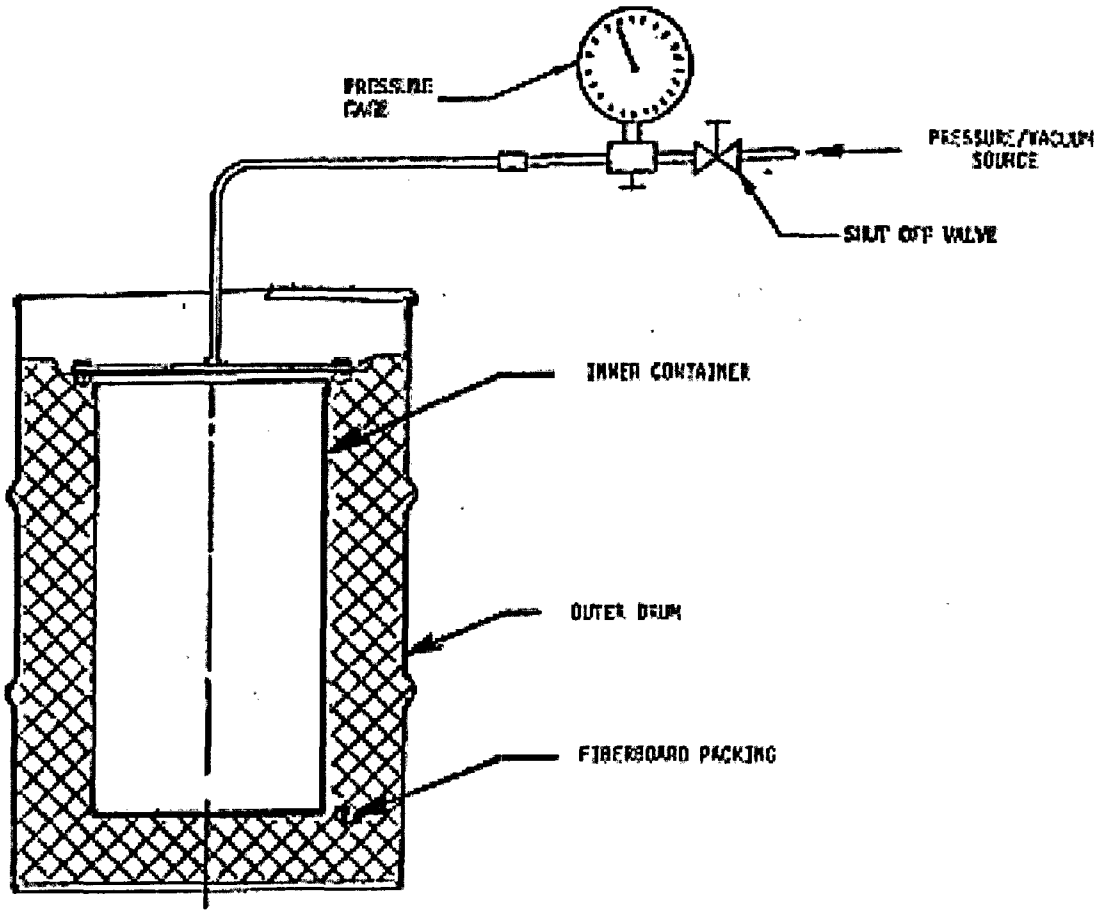


FIGURE 2.1
REDUCED & INCREASED EXTERNAL PRESSURE TESTS

FIGURE 2.2

WATER SPRAY TEST - 10 CFR 71.71(c)(6)

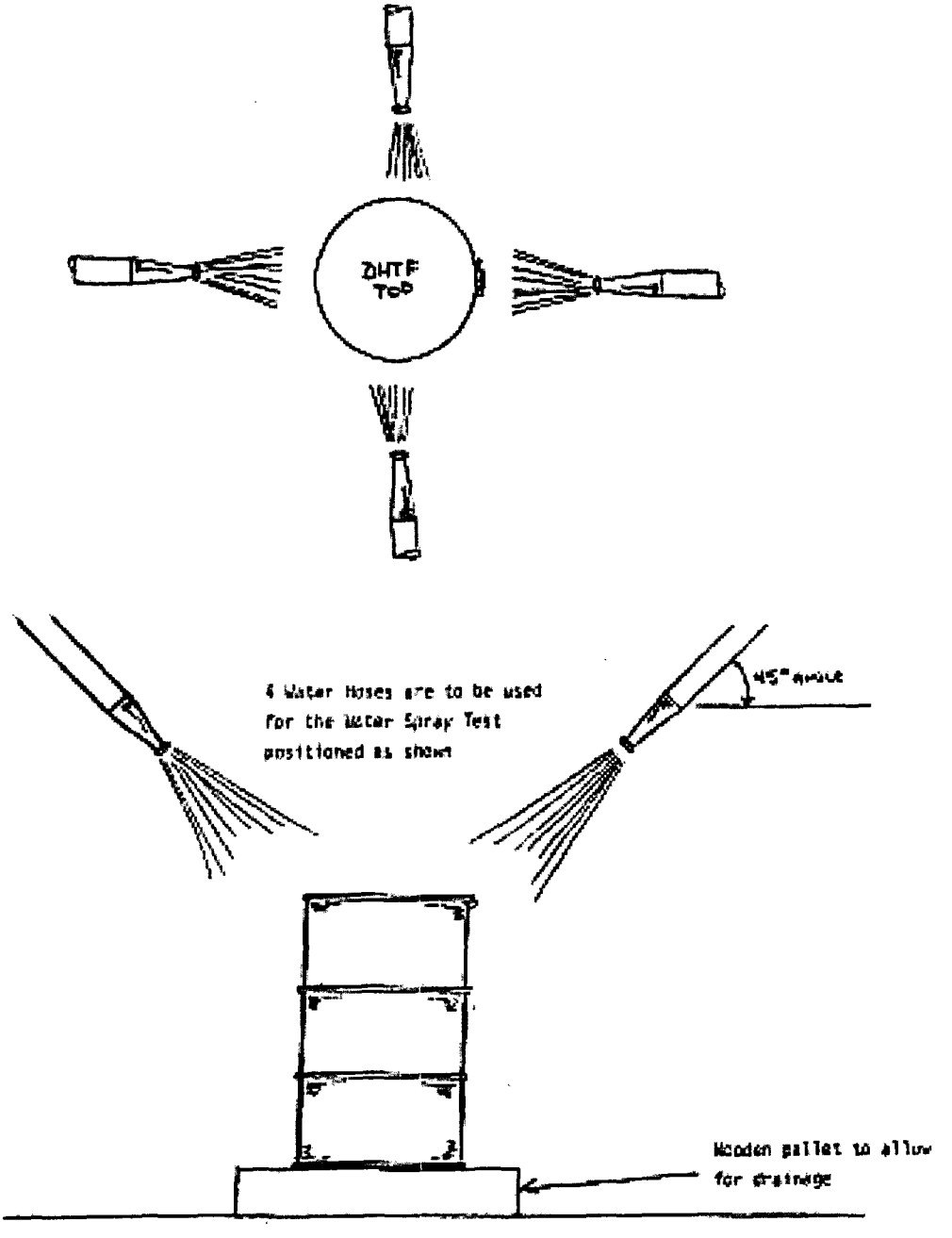
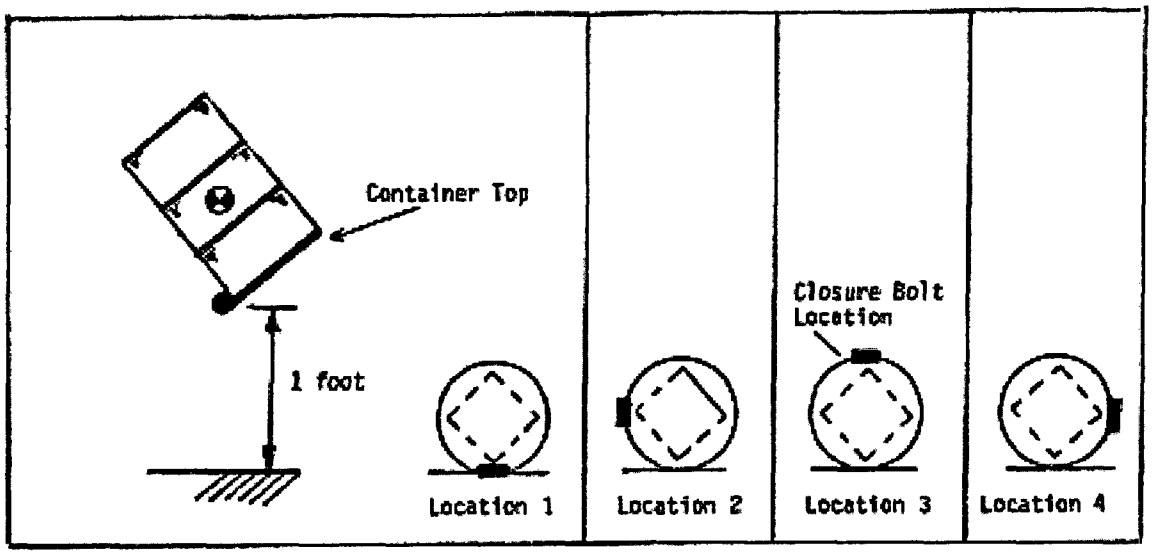


FIGURE 2 3

1 FOOT DROP TESTS - 10 CFR 71.71(c)(7)
CONTAINER NO. D01



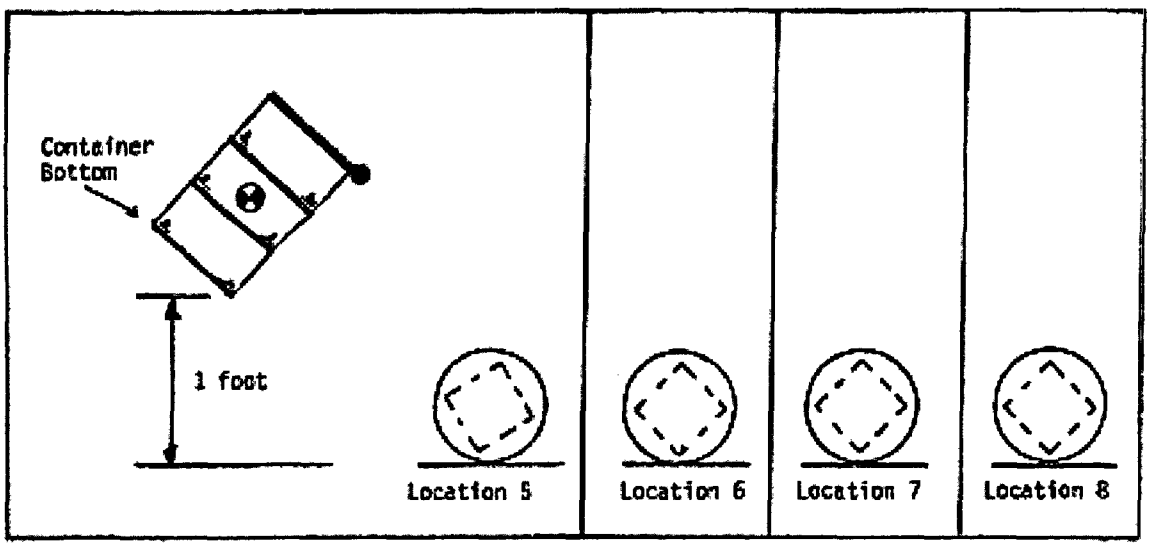
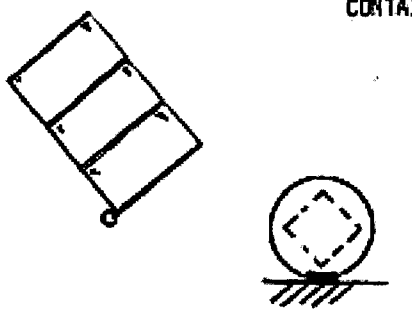
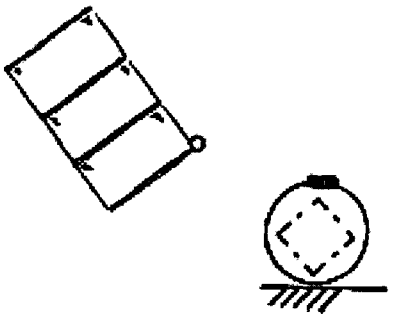


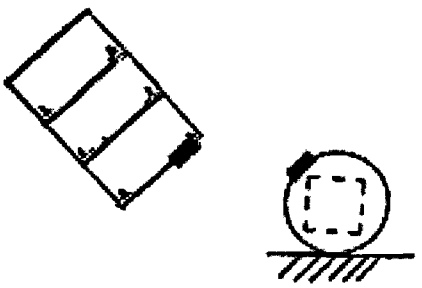
FIGURE 2.4
4 FT DROP TESTS - 10 CFR 71.71(c)(7)
CONTAINER NO. D01



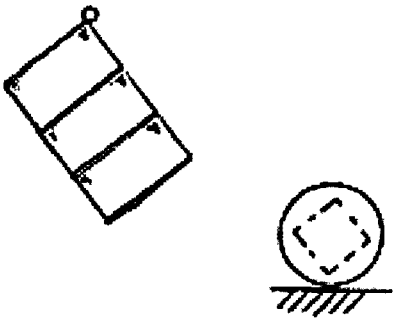
DROP #1 - at angle on Location 1



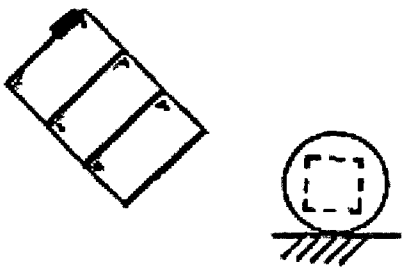
DROP #2 - at angle on Location 3



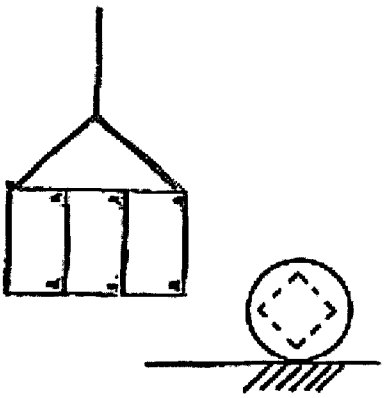
DROP # 3 - at angle on Side A



DROP #4 - At angle on Location 5 (Container Bottom)



DROP #5 - at angle on Side E



DROP #6 - Horizontal Drop on Location 4

FIGURE 2.5
PENETRATION TEST
10 CFR 71.71(c)(10)

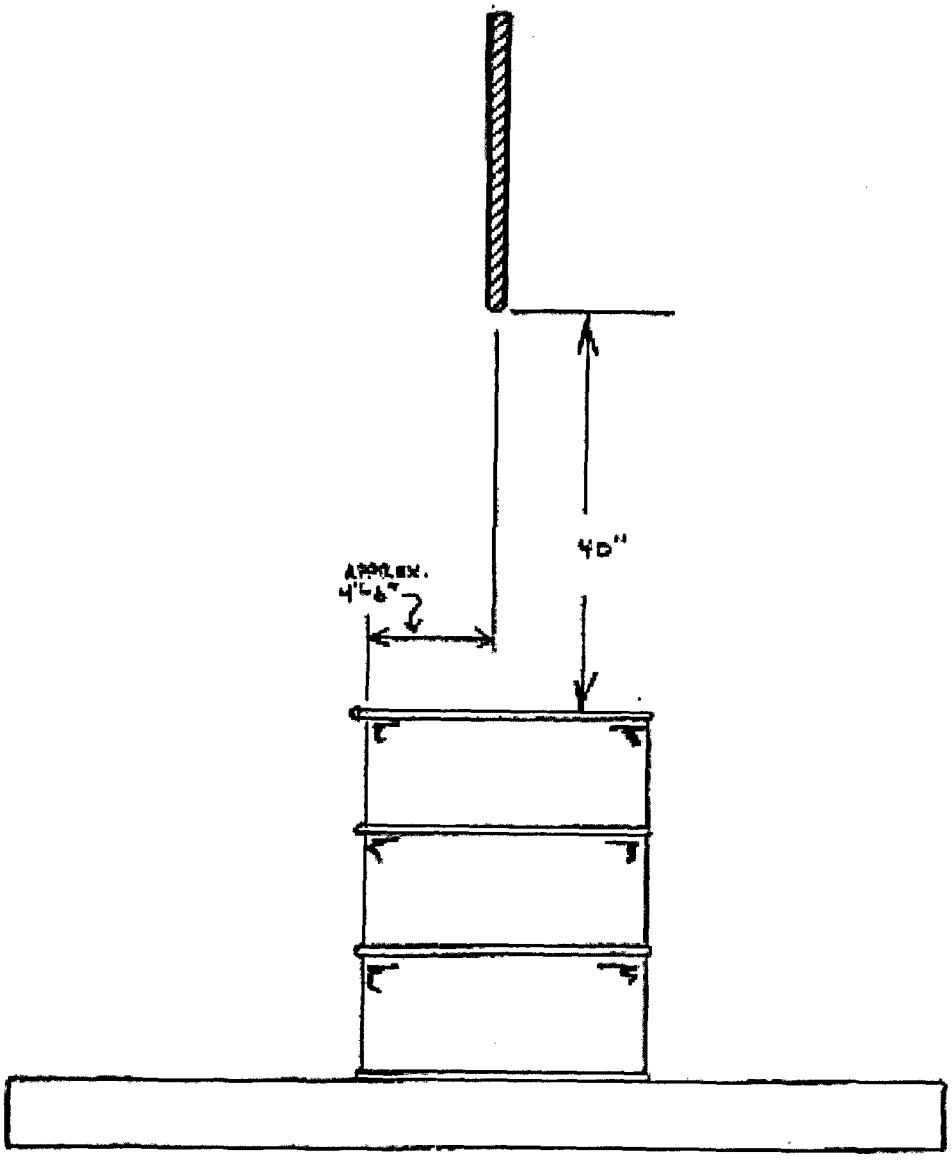
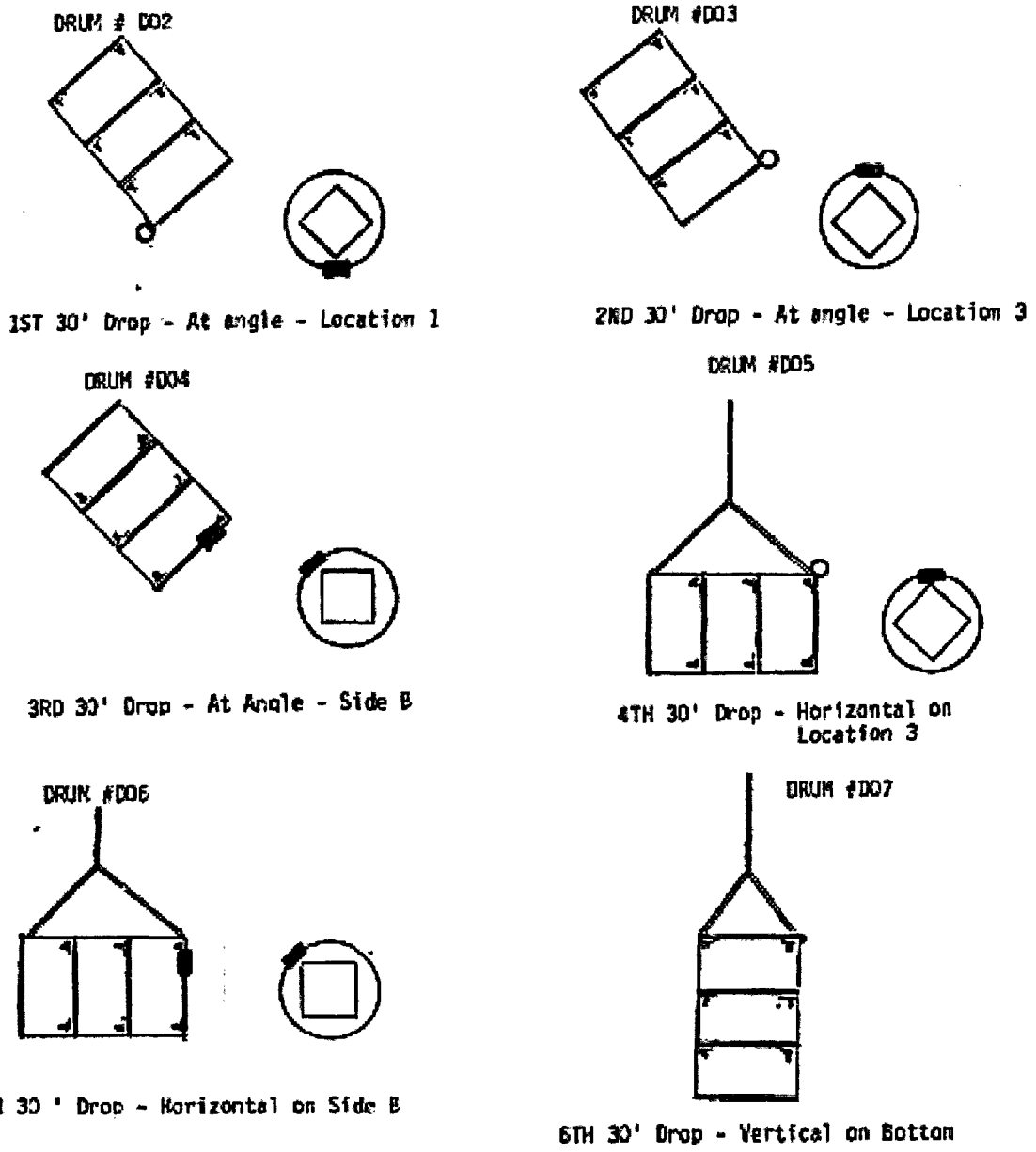


FIGURE 2.6
30' DROP TESTS
10 CFR 71.73(c)(1)



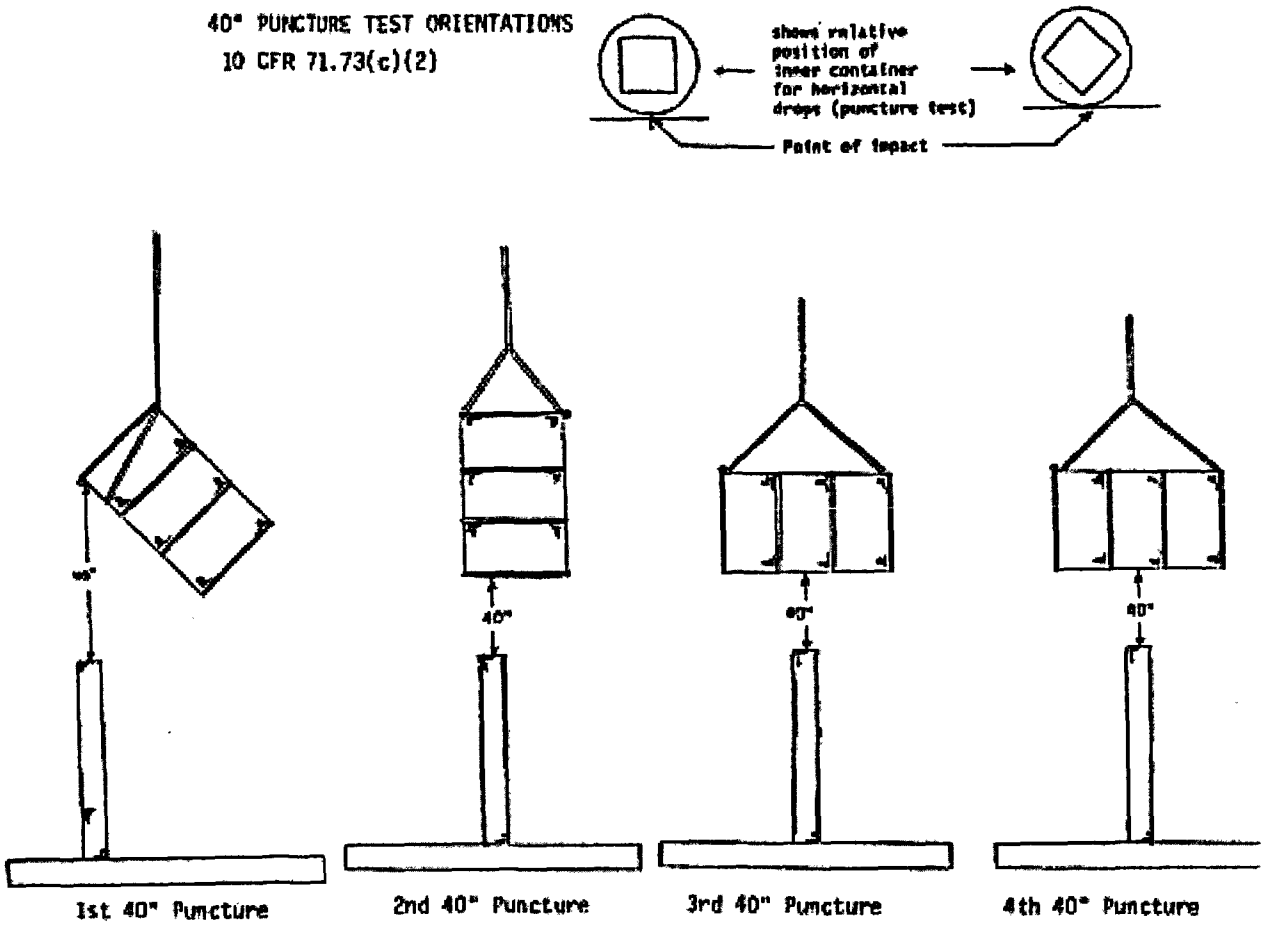


FIGURE 2.7

ALL 4 40" PUNCTURE TESTS PERFORMED ON
DRUMS 002 THROUGH 007

FIGURE 2.8

CONTAINER ORIENTATIONS

FOR 1 FOOT, 4 FOOT, & 30 FOOT ANGLE DROPS

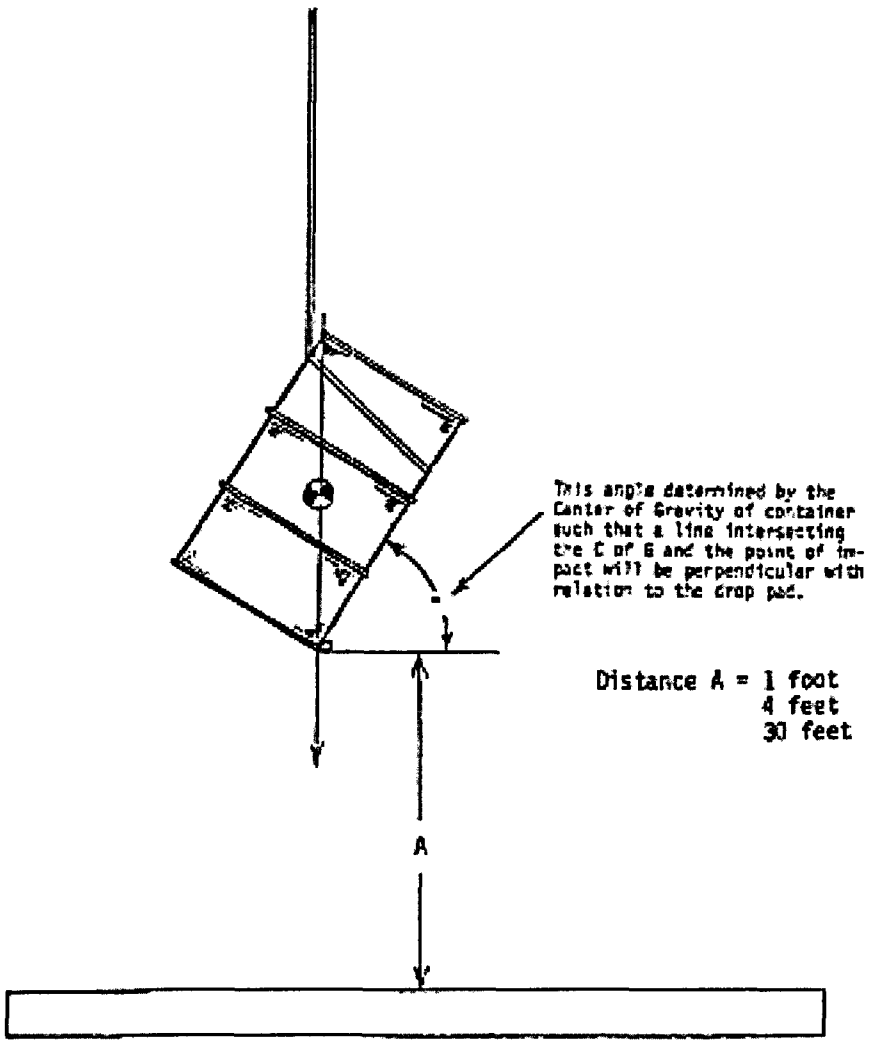


FIGURE 2.9

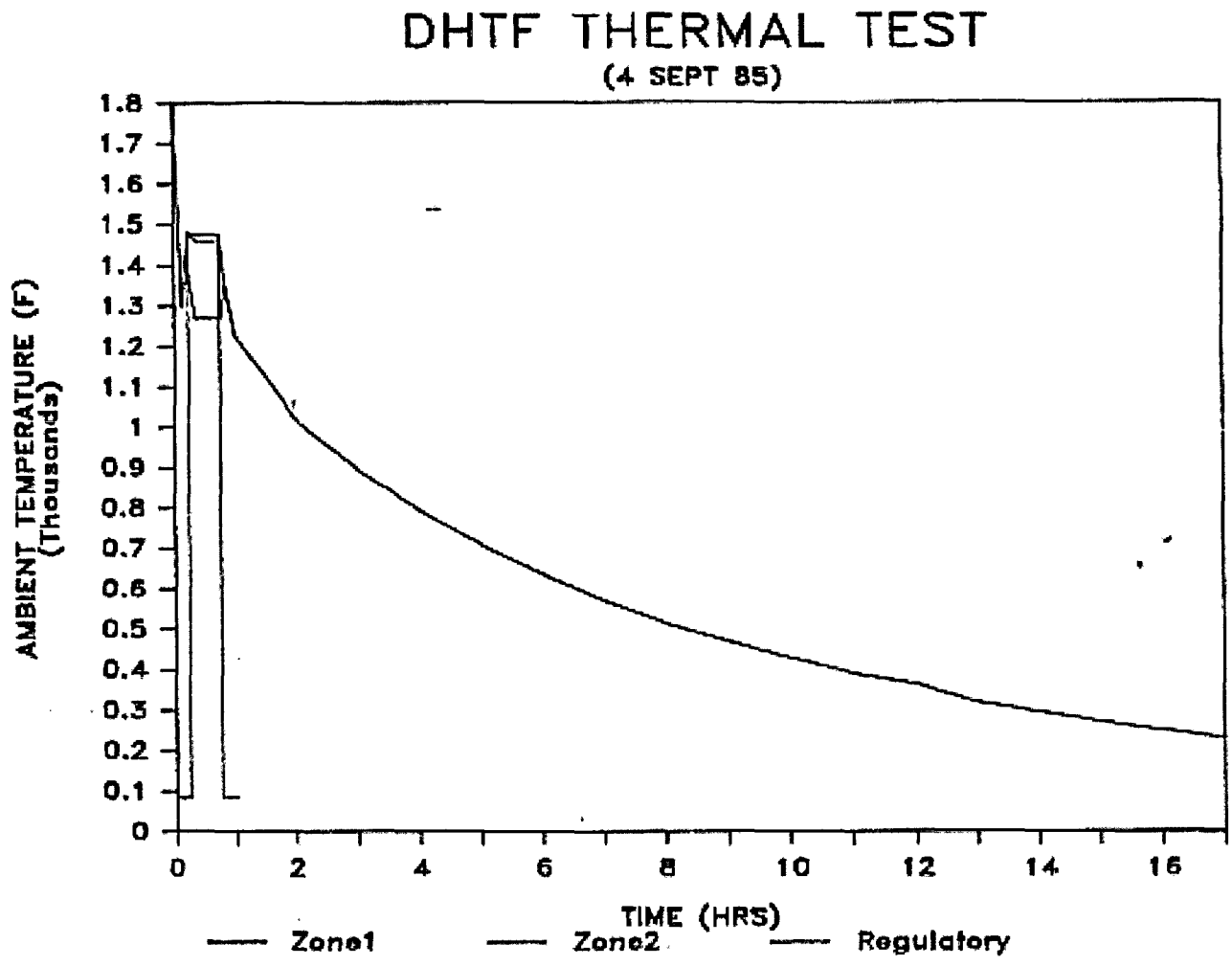
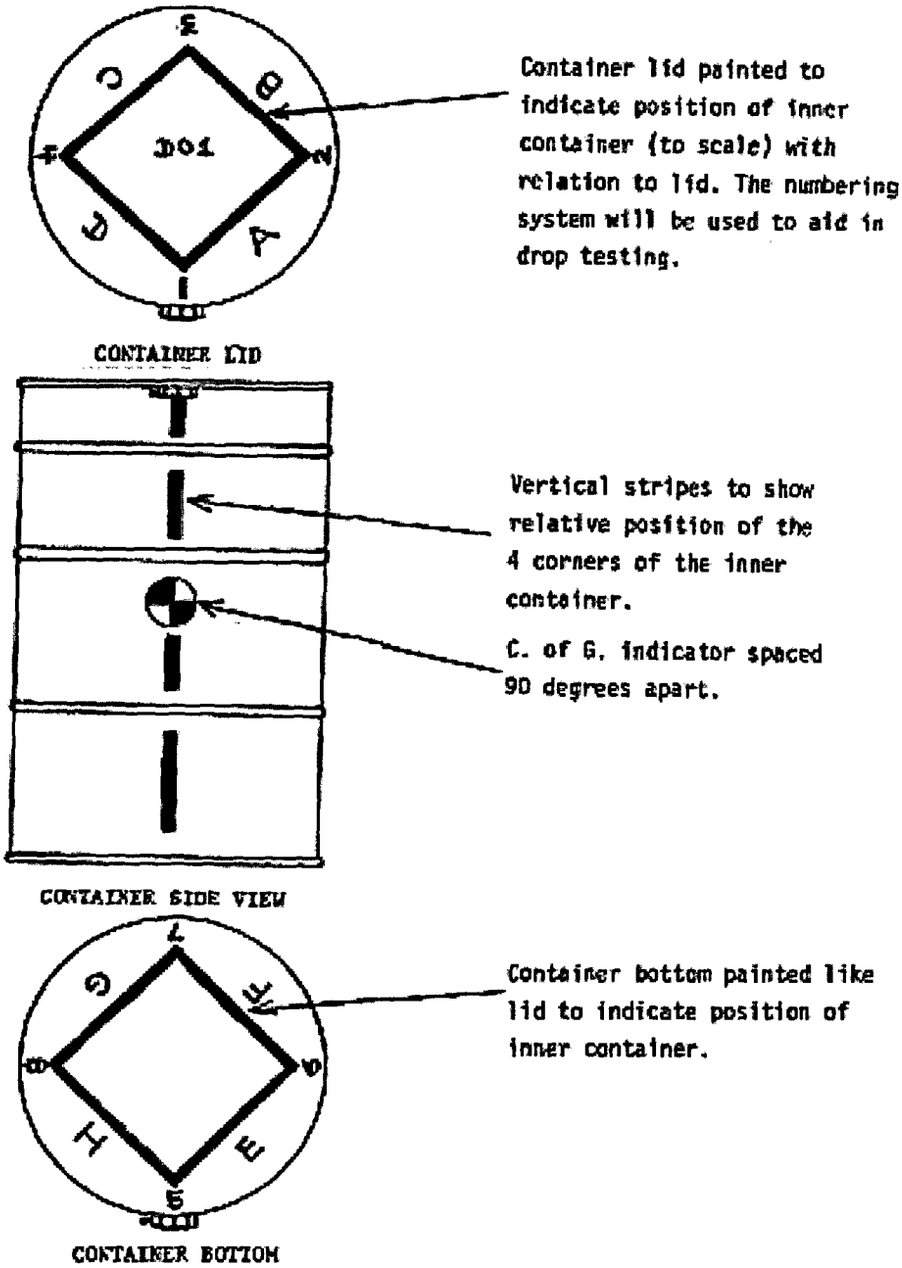

DHTF THERMAL TEST
(4 SEPT 85)
AMBIENT TEMPERATURE (F)
(Thousands)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
TIME (HRS)
Zone1
Zone2
Regulatory

FIGURE 2.10
MARKING & ORIENTATIONS ON PROTOTYPE DRUMS



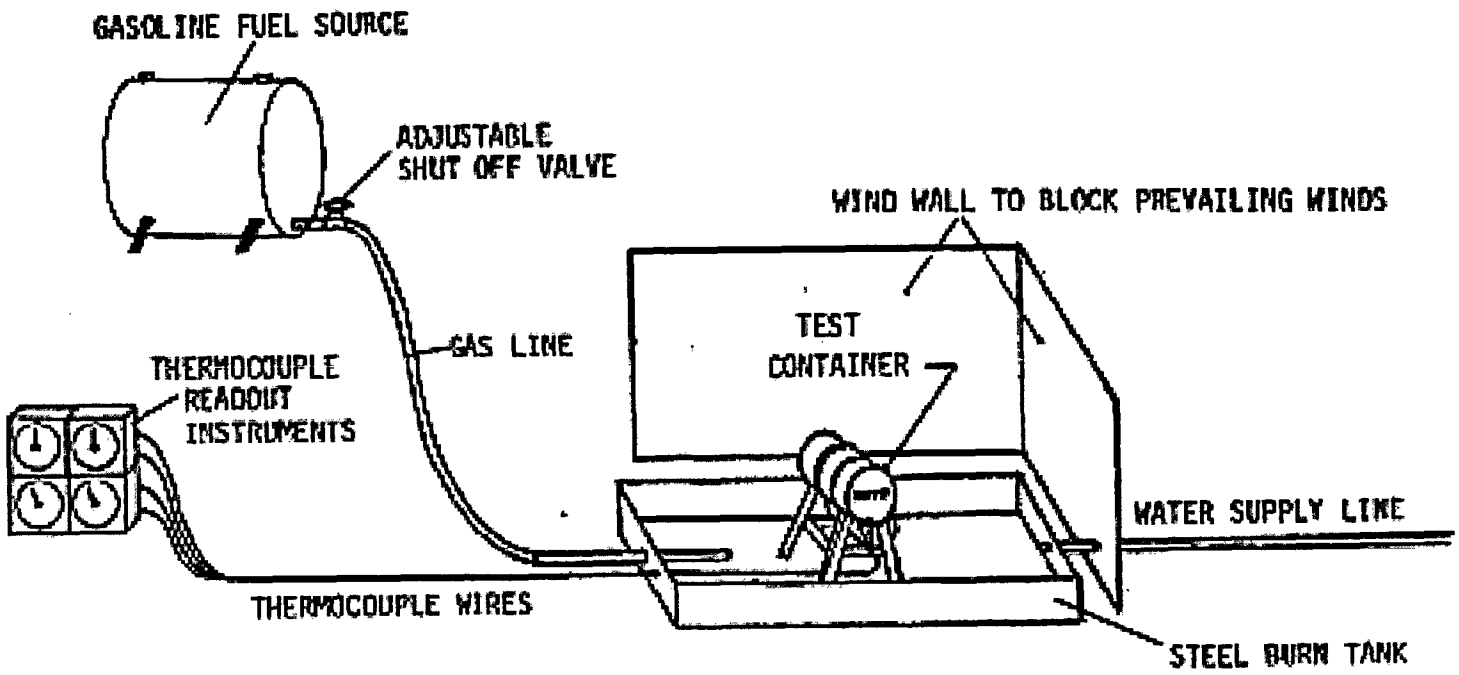
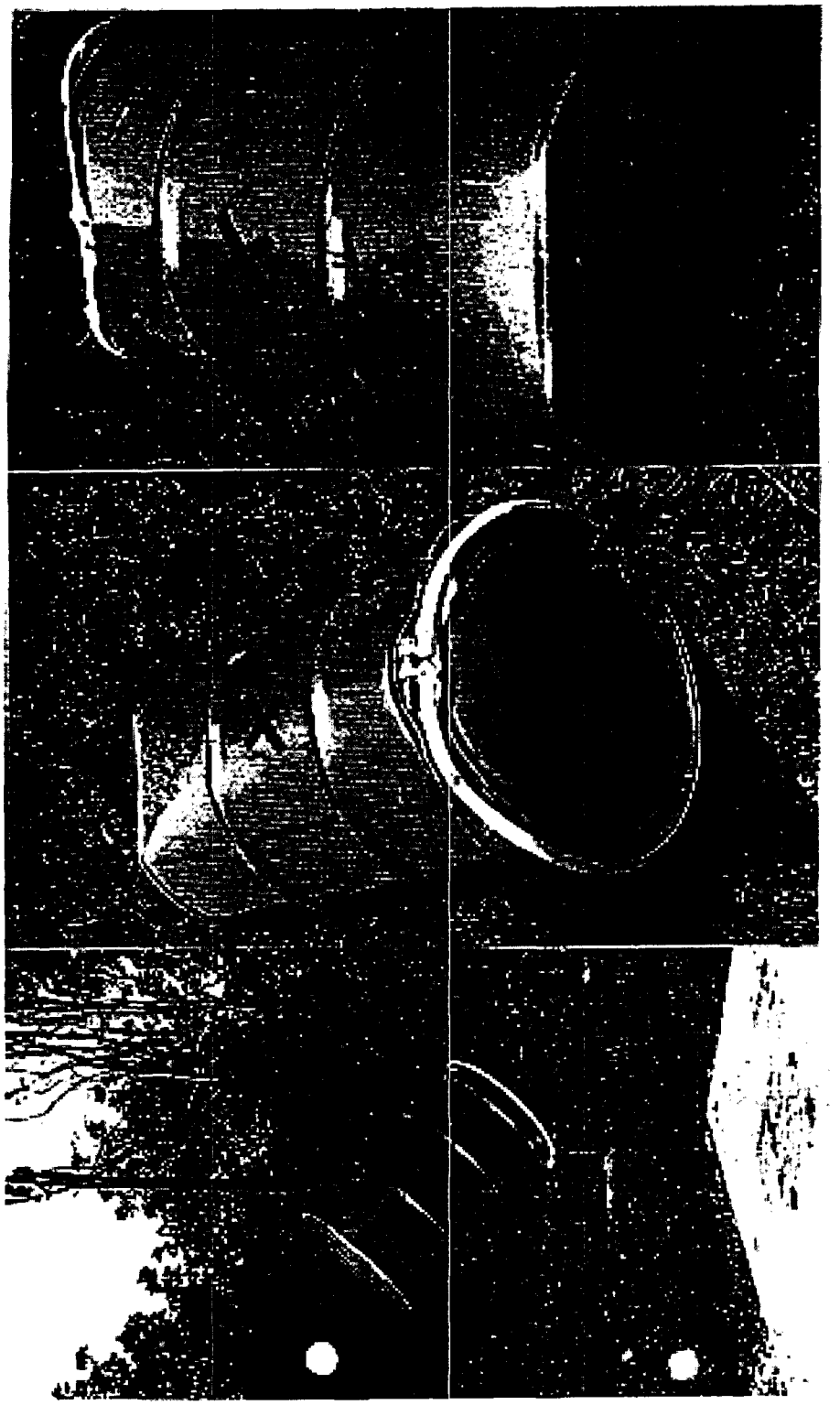


FIGURE 2.11

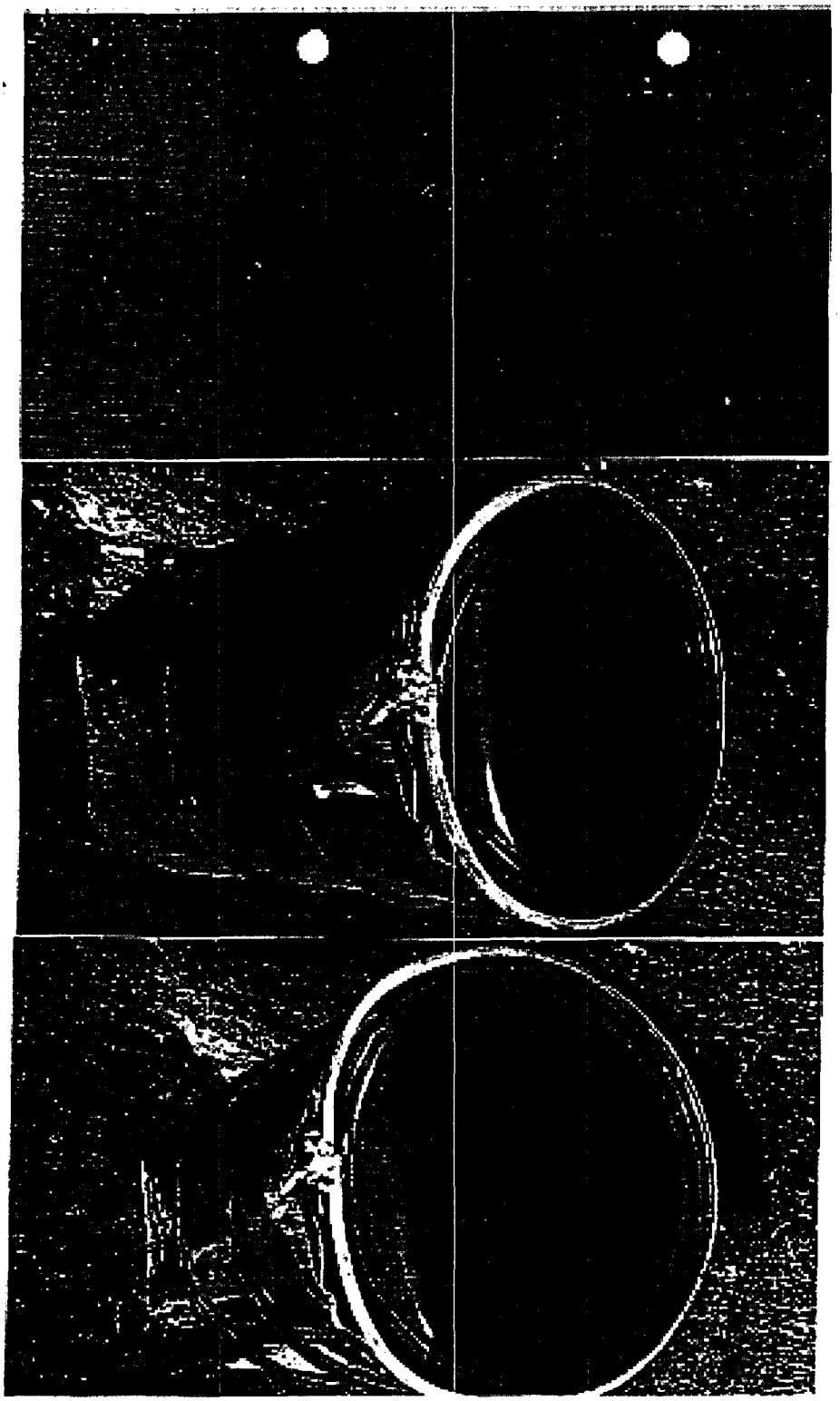
SCHEMATIC OF OPEN AIR BURN SET UP (DRUMS D08 AND D09)



30' DROP - DRUM DOR

30' DROP - DRUM DOR

30' DROP - DRUM DOR



30' DROP - DRUM C09

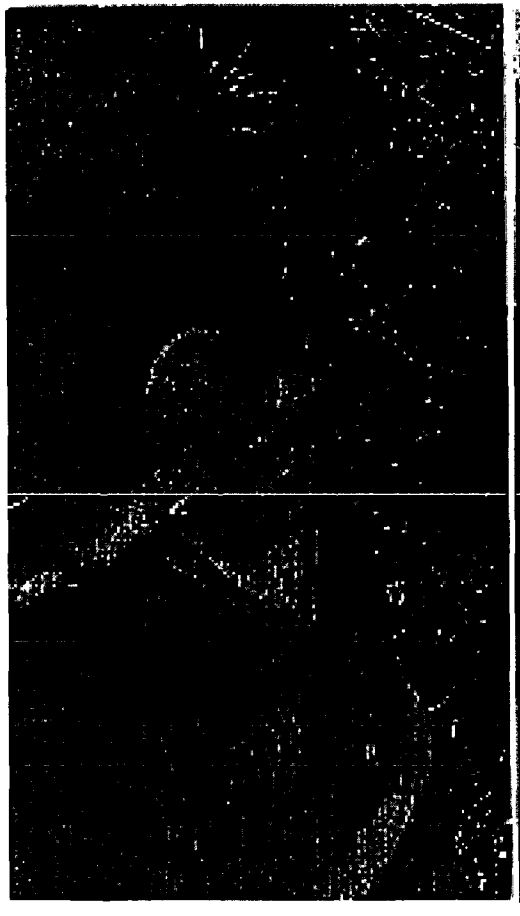
30' DROP - DRUM C09

30' DROP - DRUM C09

1ST 40" PUNCTURE - DRUM 008

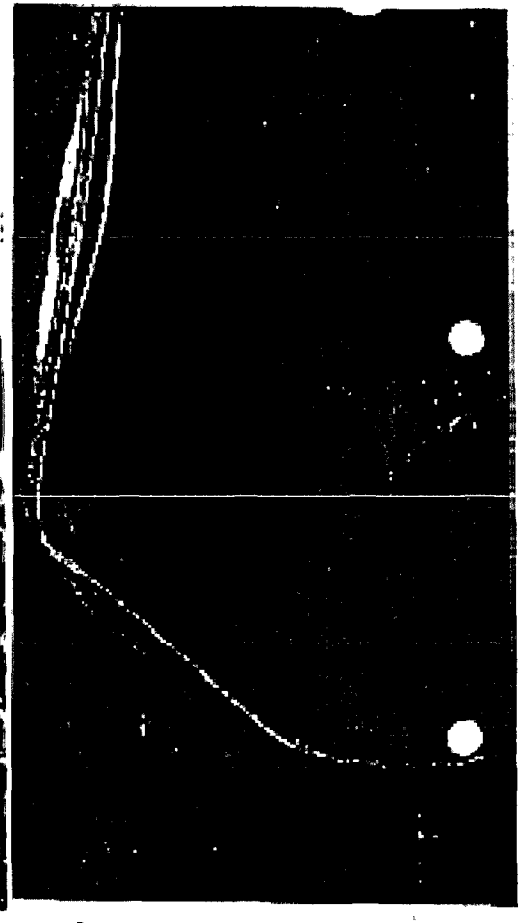
DAMAGE FROM 1ST 40" PUNCTURE - DRUM 008

2ND 40" PUNCTURE - DRUM 008

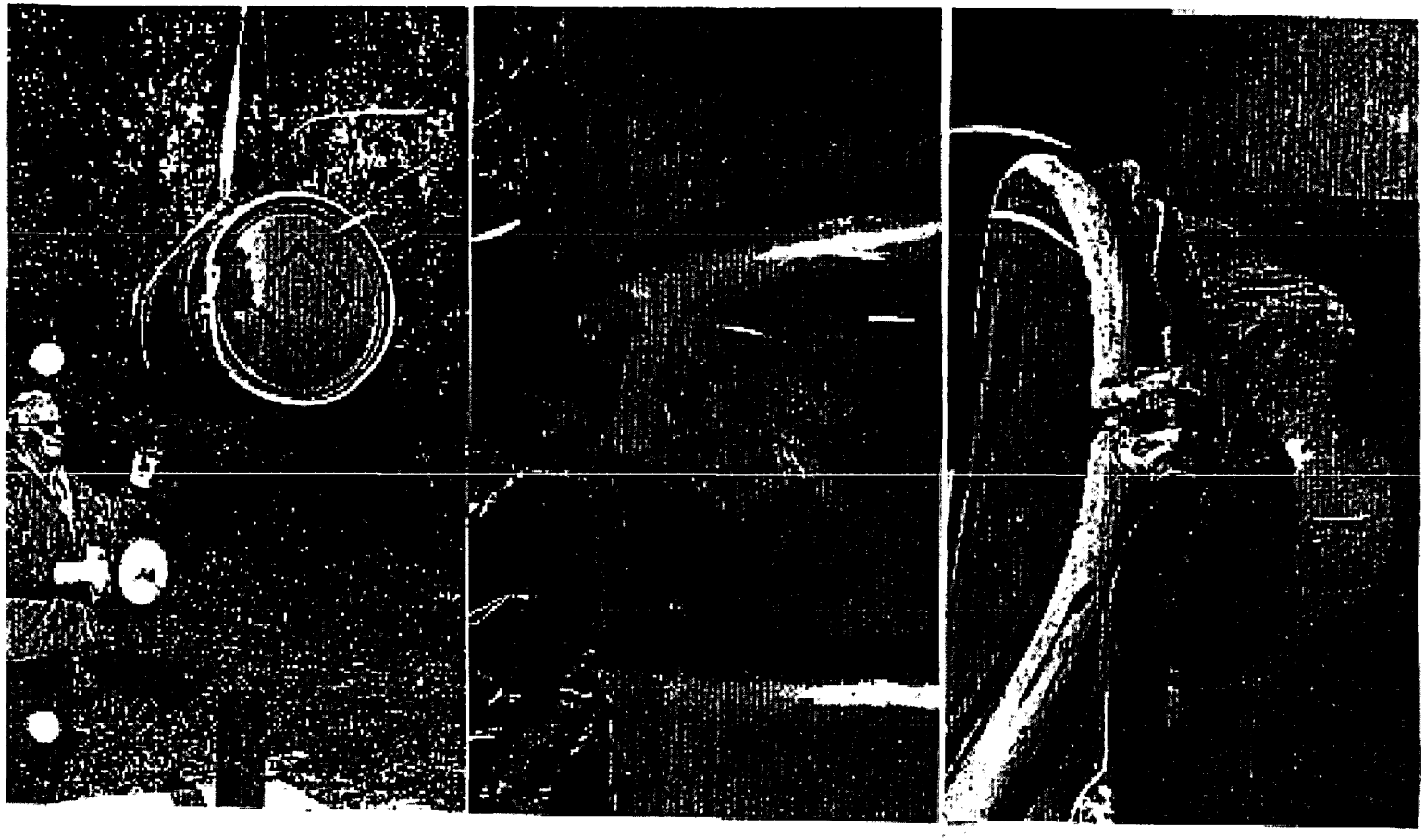


DAMAGE FROM 2ND 40" PUNCTURE - DRUM DOB

3RD 40" PUNCTURE - DRUM DOB



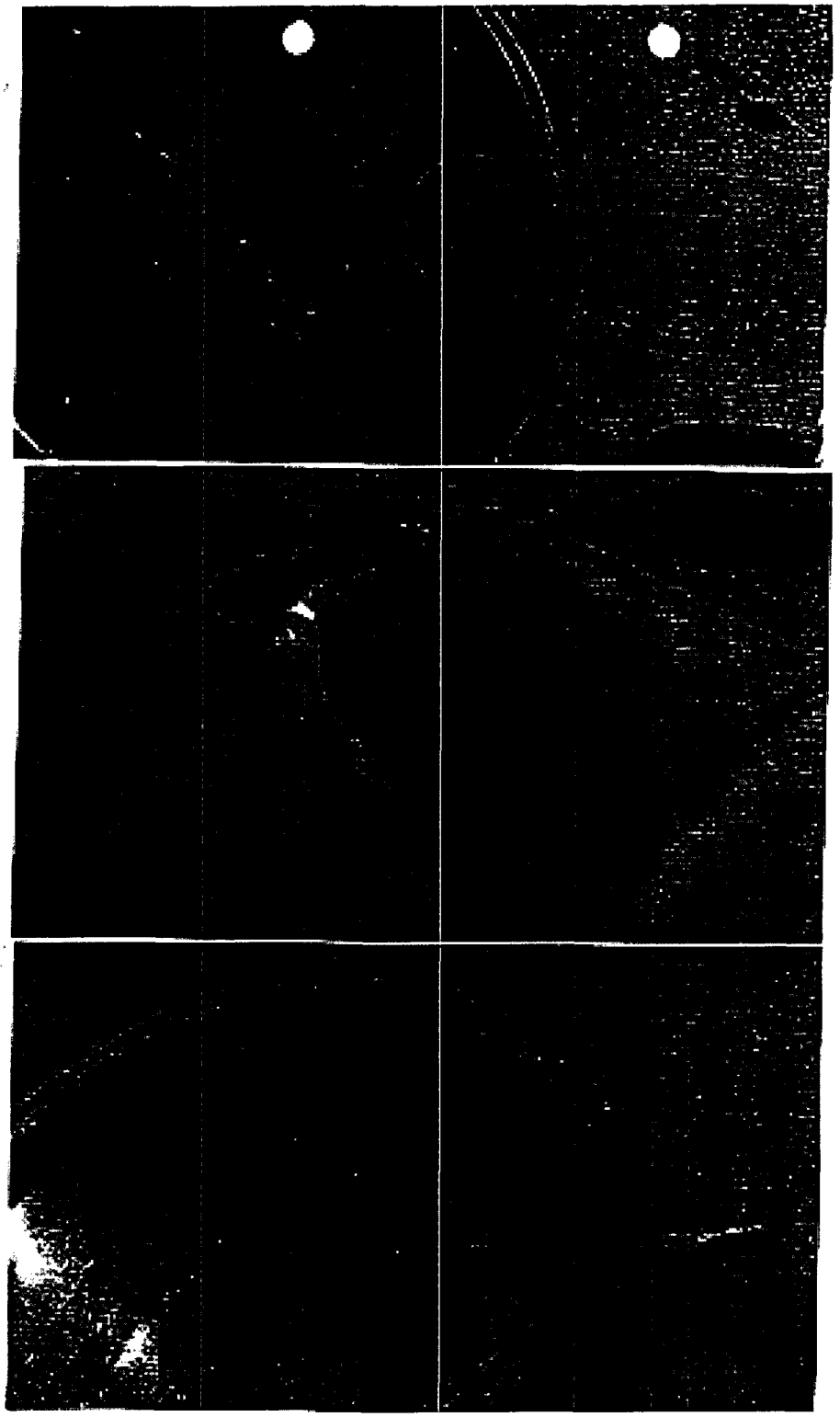
DAMAGE FROM 3RD 40" PUNCTURE - DRUM DOB



4TH 40" PUNCTURE - DRUM D08

DAMAGE FROM 4TH 40" PUNCTURE - DRUM D08

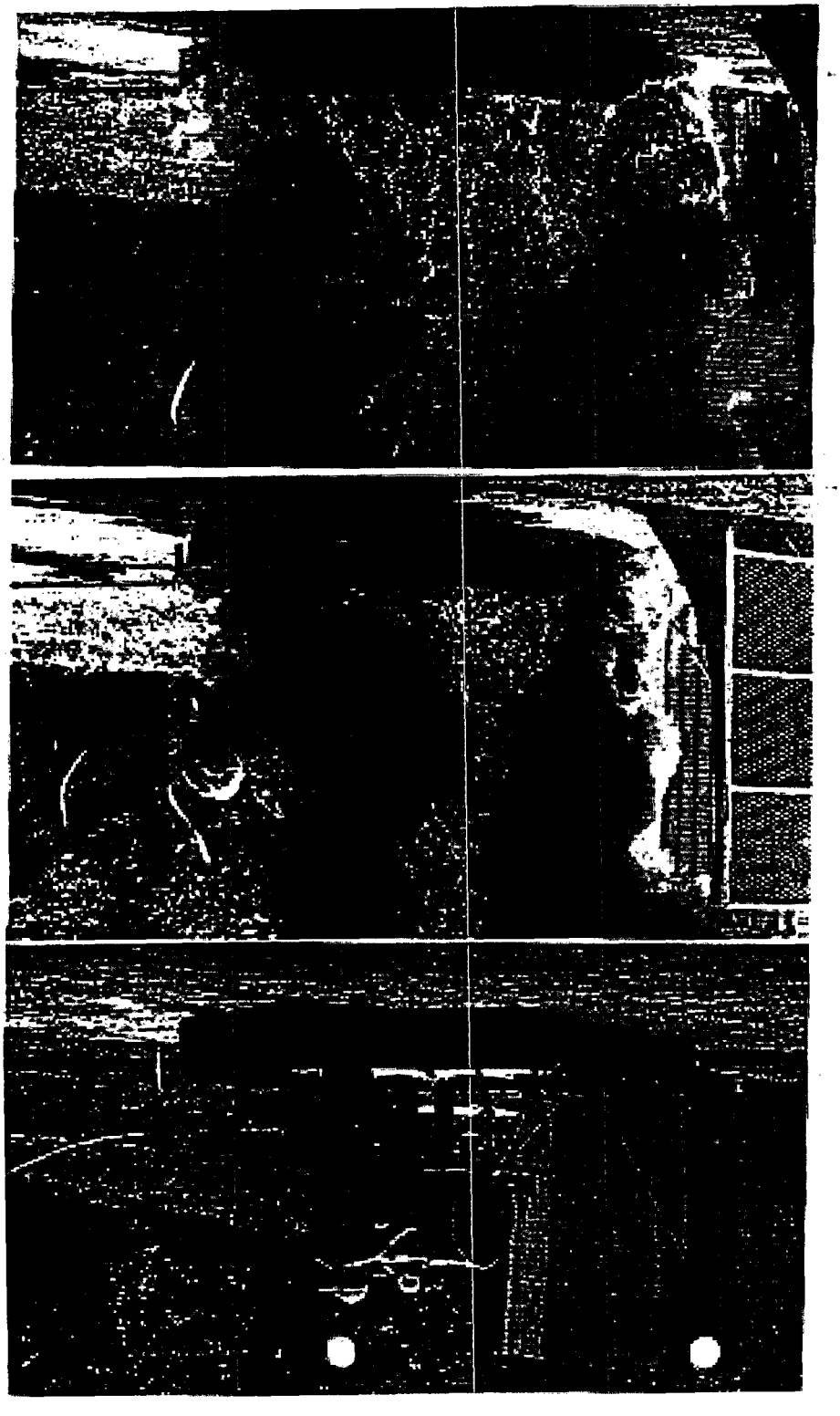
1ST 40" PUNCTURE - DRUM D09



2ND 40" PUNCTURE - DRUM 009

3RD 40" PUNCTURE - DRUM 009

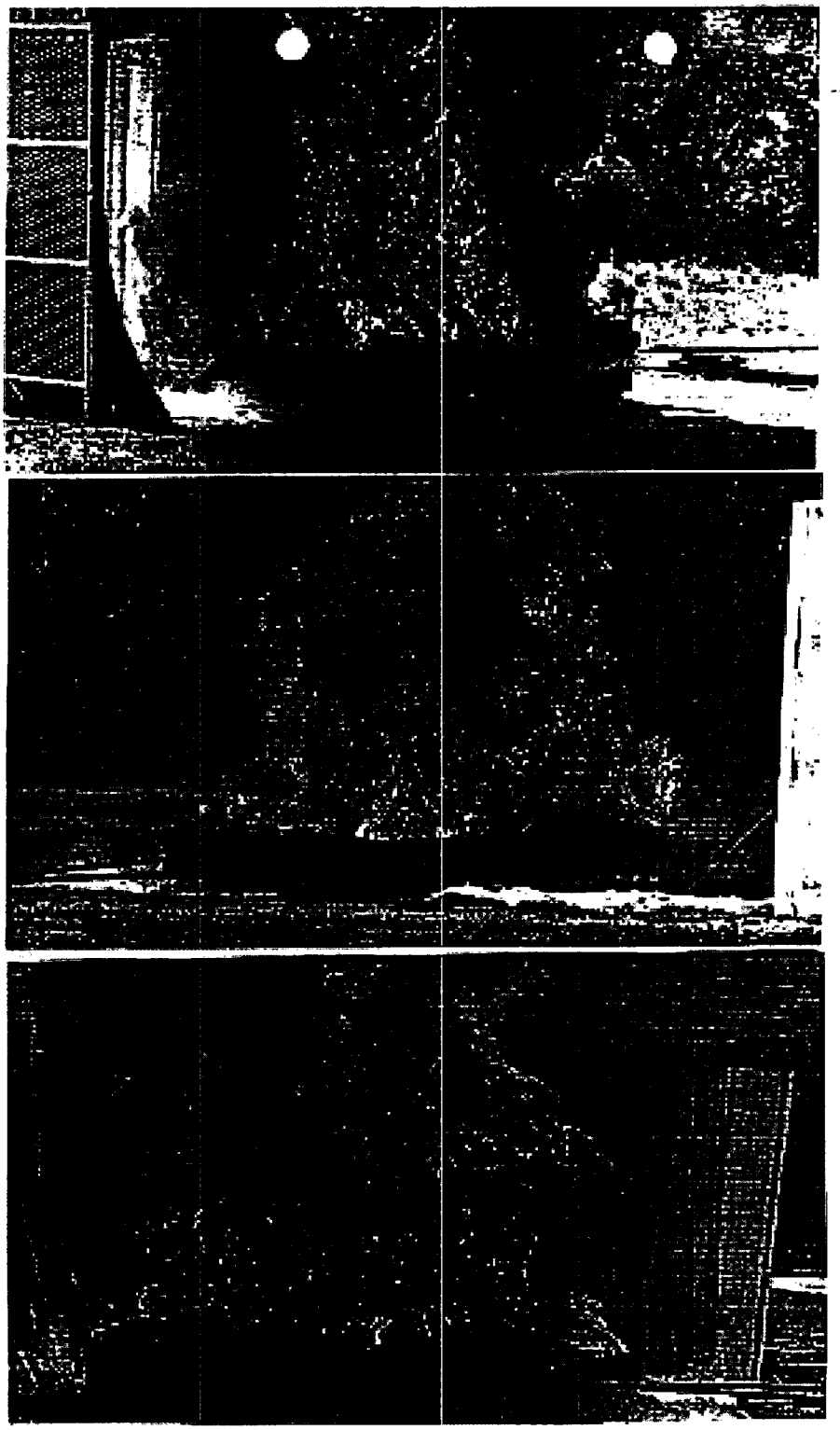
4TH 40" PUNCTURE - DRUM 009



OPEN FIRE TEST SETUP - DRUM 003

DURING FIRE TEST - DRUM 003

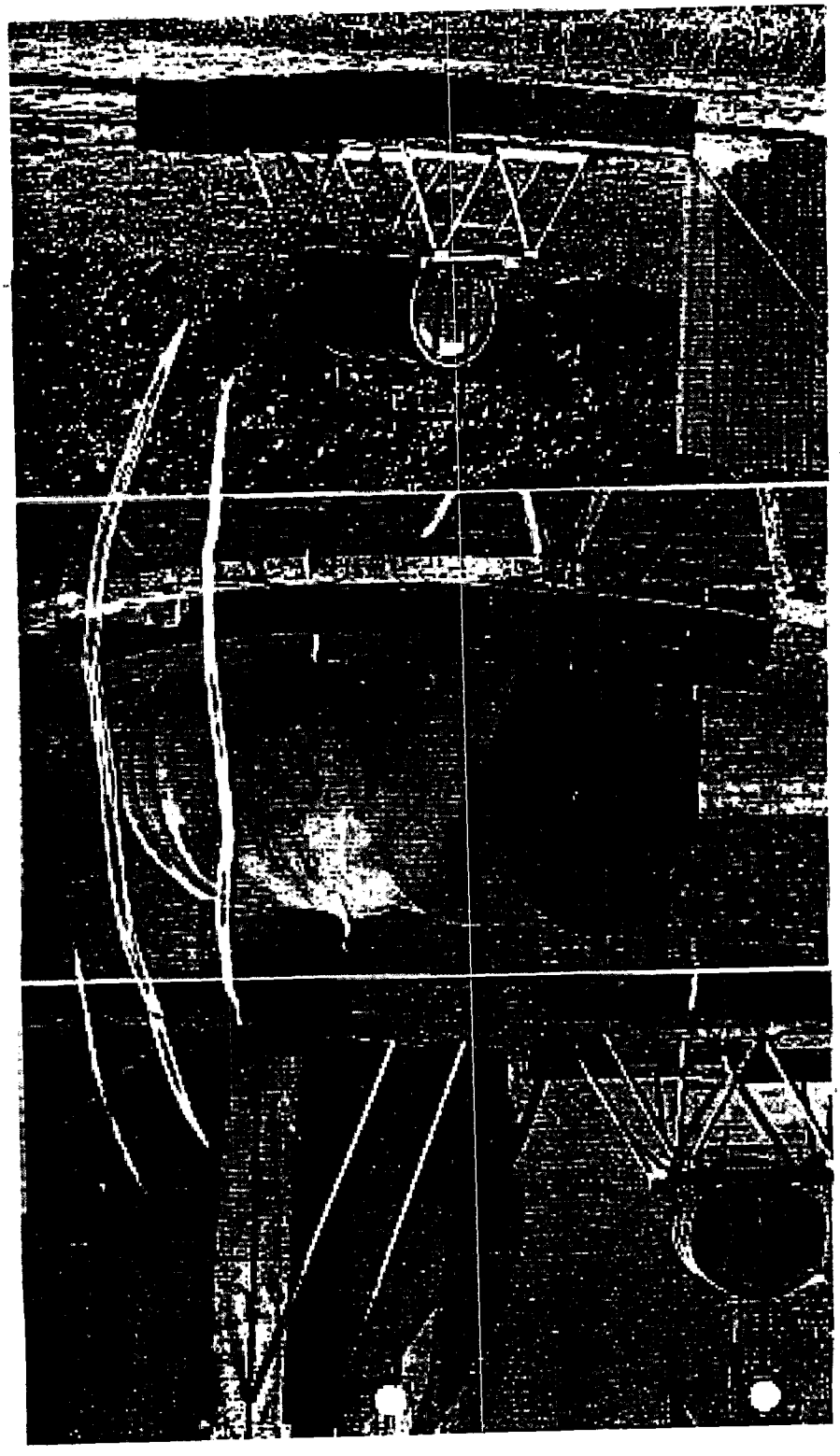
DURING FIRE TEST - DRUM 000



DURING FIRE TEST - DRUM 008

DURING FIRE TEST - DRUM 009

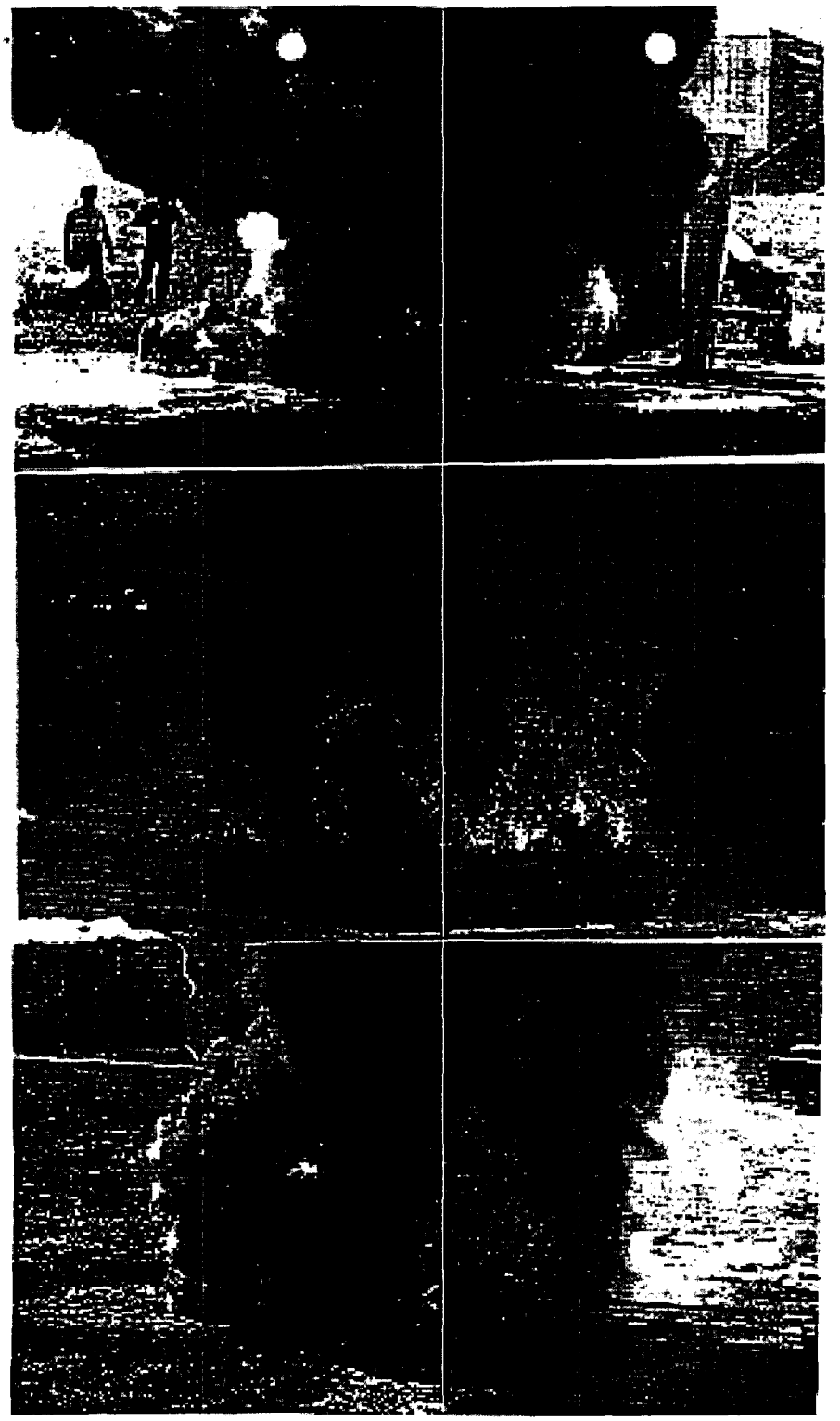
DURING FIRE TEST - DRUM 010



OPEN FIRE TEST SETUP - DRUM D09

AFTER FIRE TEST - DRUM D08

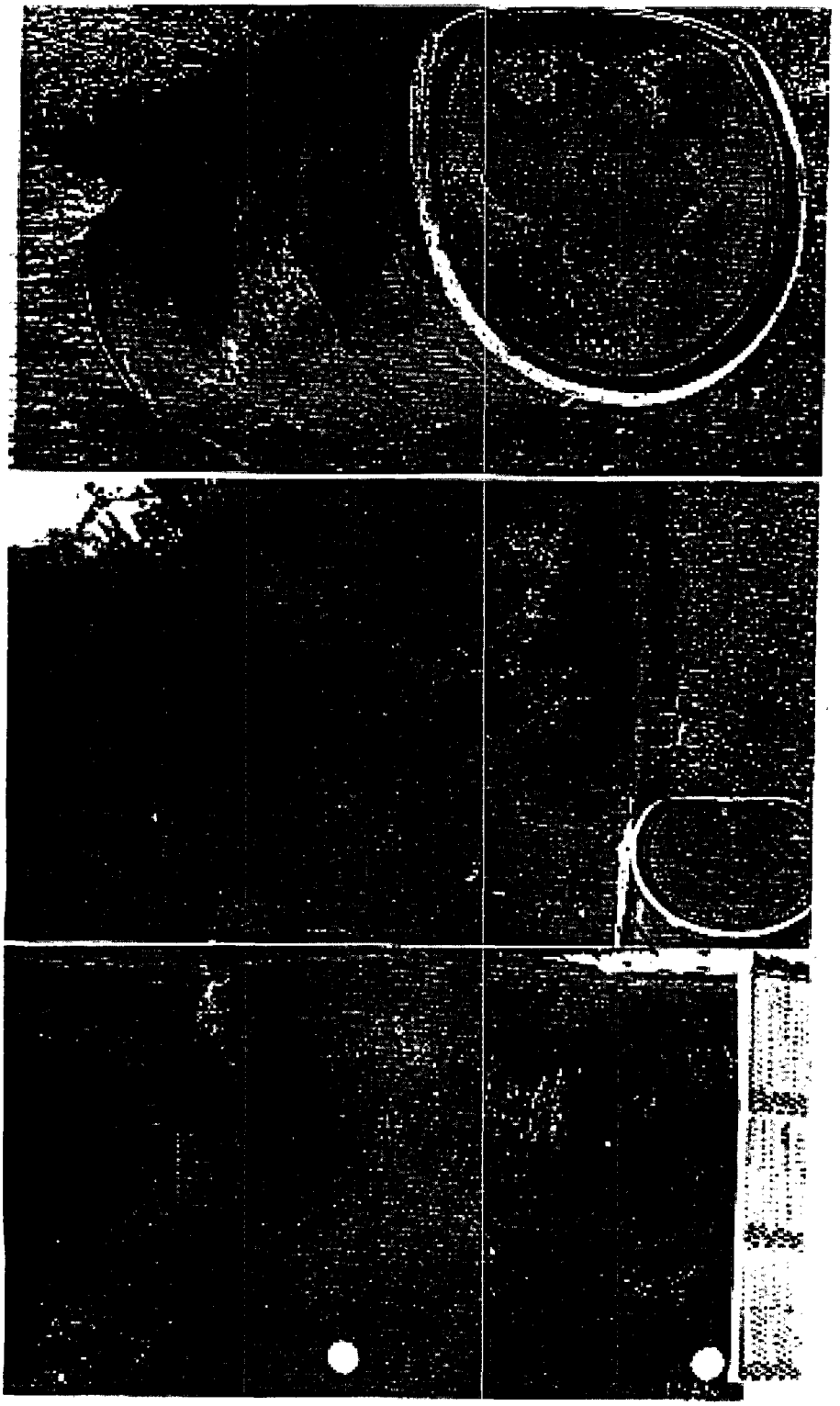
AFTER FIRE TEST - DRUM D08



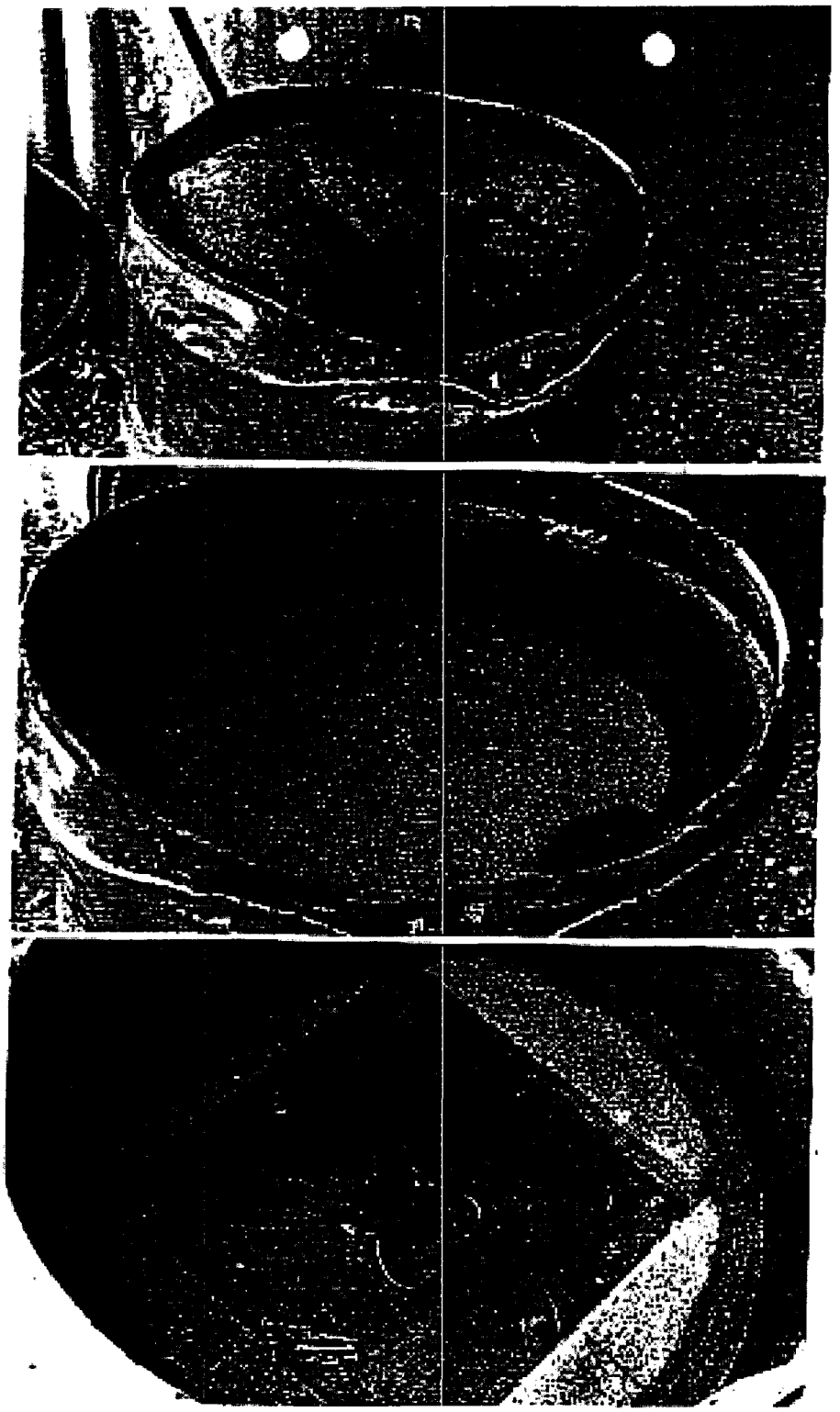
DURING FIRE TEST - DRUM D09

DURING FIRE TEST - DRUM D09

DURING FIRE TEST - DRUM D09



DURING FIRE TEST - DRUM D09 — DURING FIRE TEST - DRUM D09 — AFTER BURN TEST - DRUM D09



POST FIRE TEST INSPECTION - DRUM 008

POST FIRE TEST INSPECTION - DRUM 008

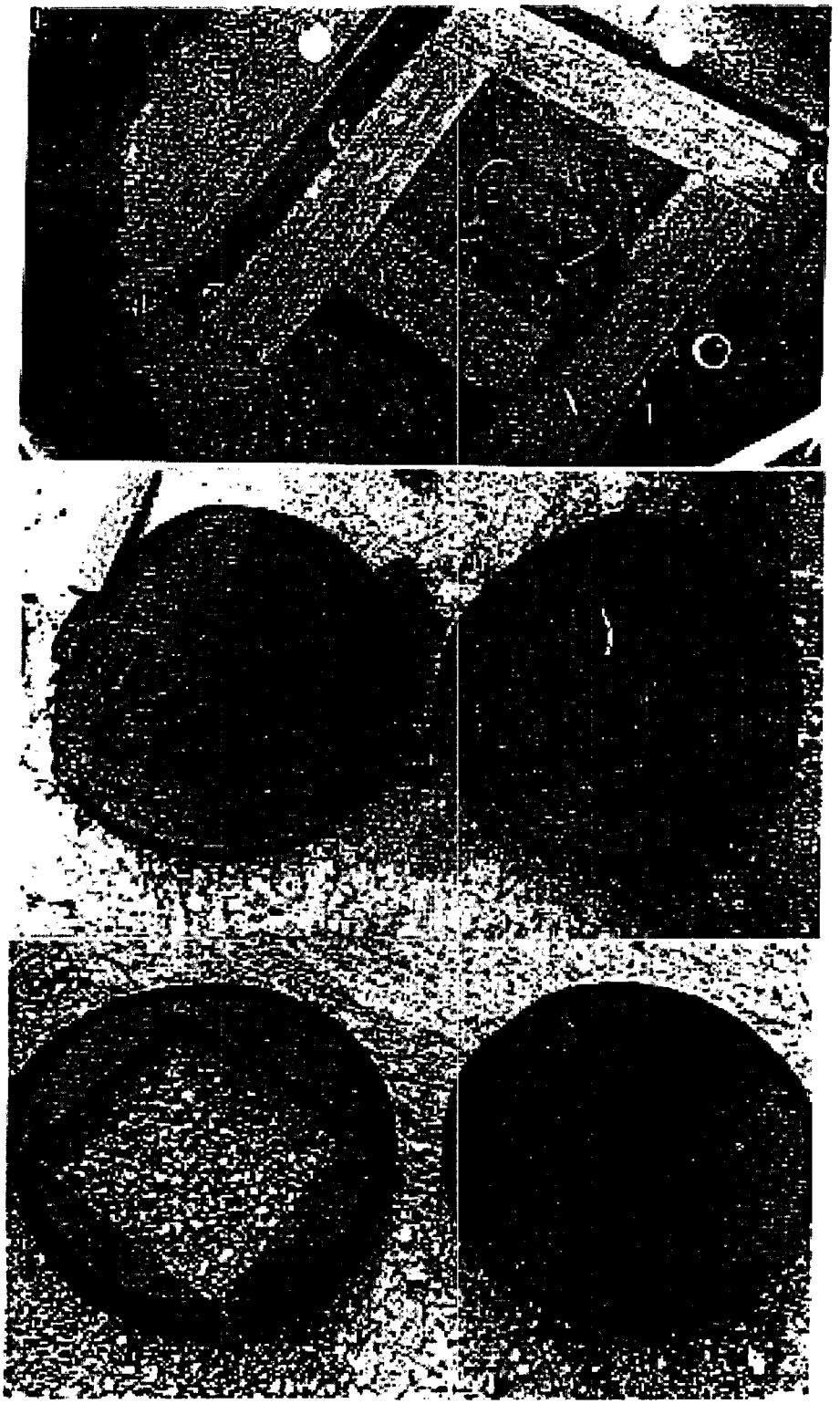
POST FIRE TEST INSPECTION - DRUM- 008

POST FIRE TEST INSPECTION - DRUM 008

FIBERBOARD RINGS - DRUM 008

FIBERBOARD RINGS - DRUM 008

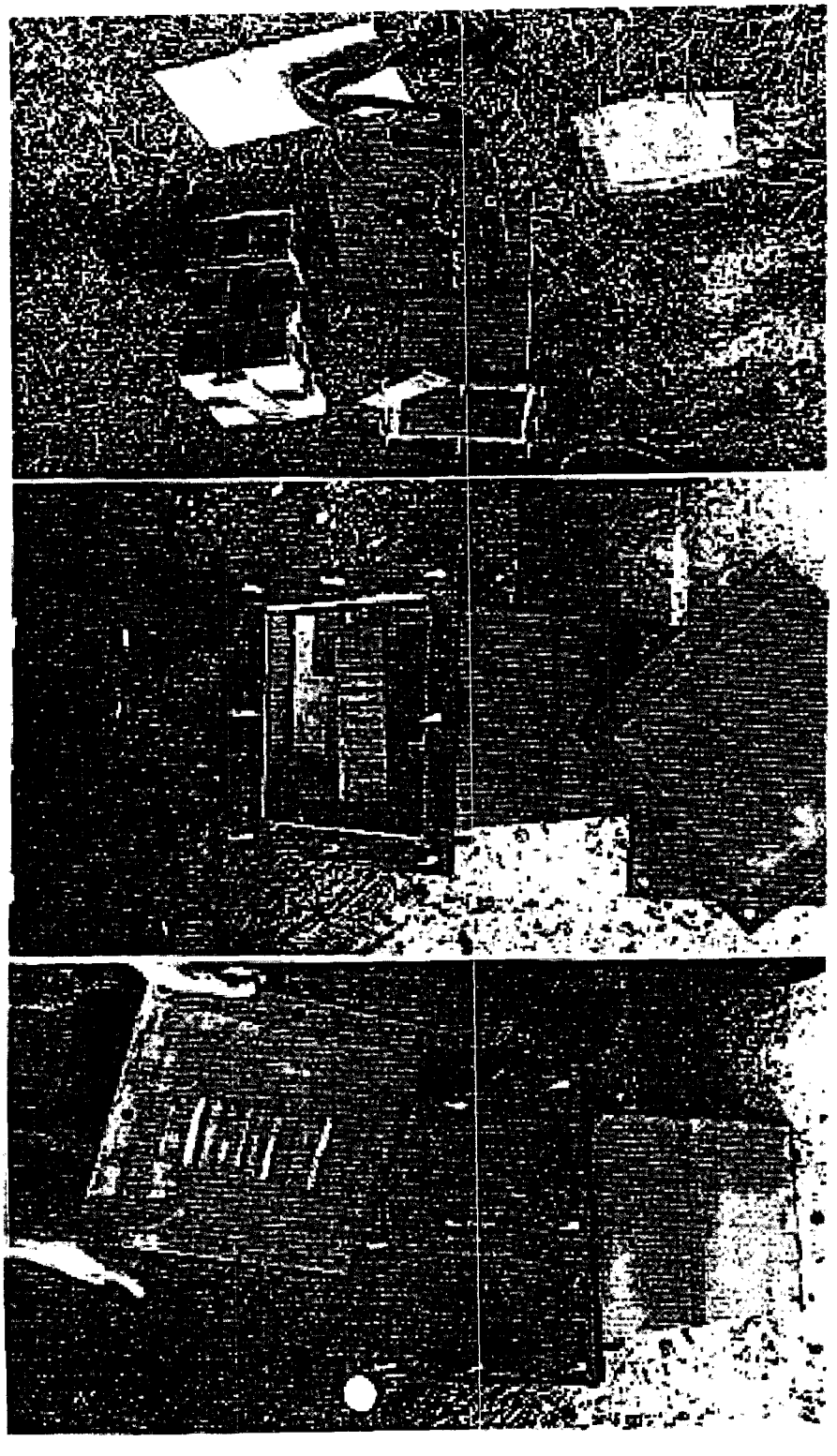
FIBERBOARD RINGS - DRUM 008
FIBERBOARD RINGS - DRUM 008
FIBERBOARD RINGS - DRUM 008



POST FIRE TEST INSPECTION - CAMM D09

FIBERBOARD RINGS - CAMM D09

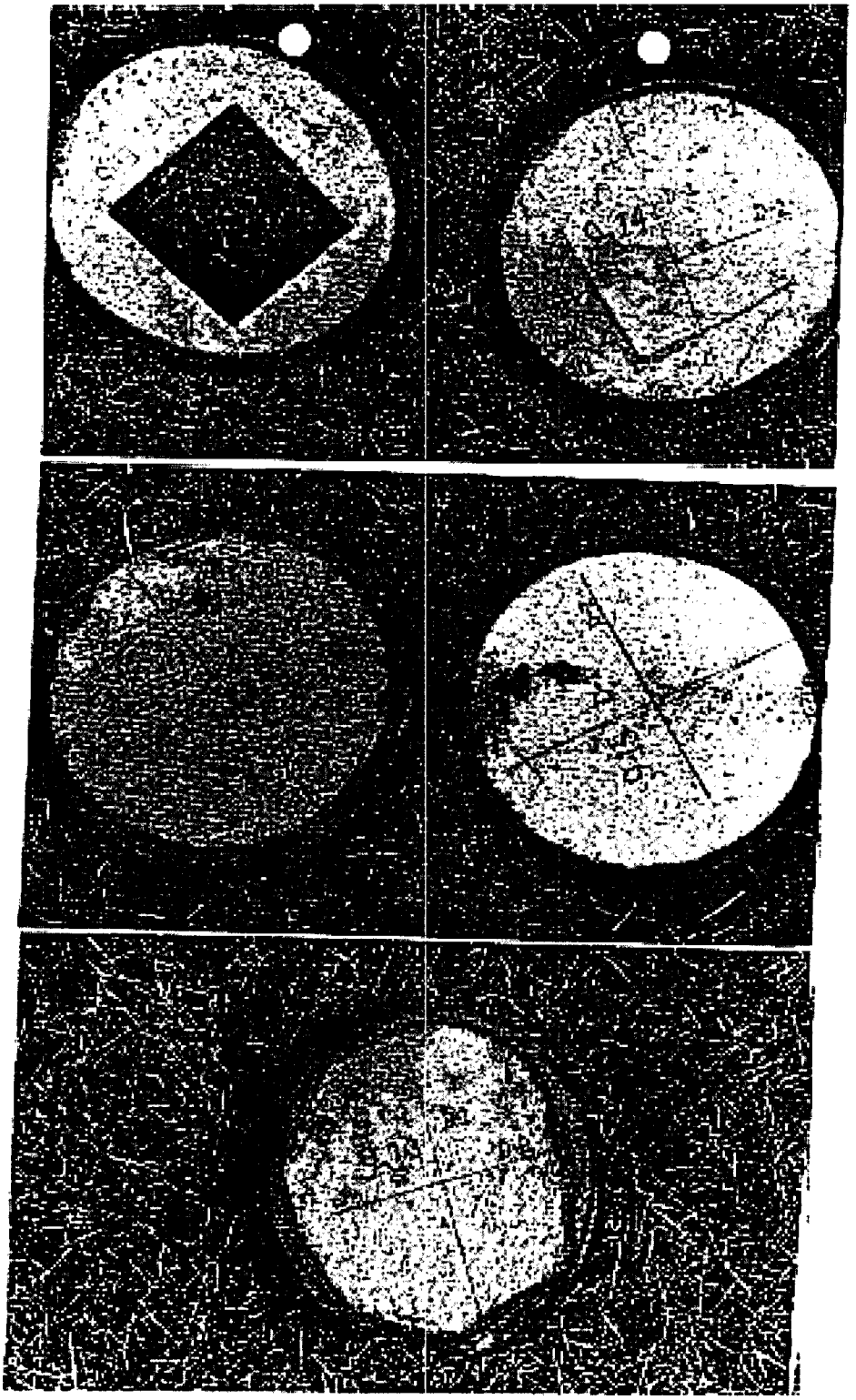
FIBERBOARD RINGS - CAMM D09



INNER CONTAINER - DRUM 009

INNER CONTAINER - DRUM 009

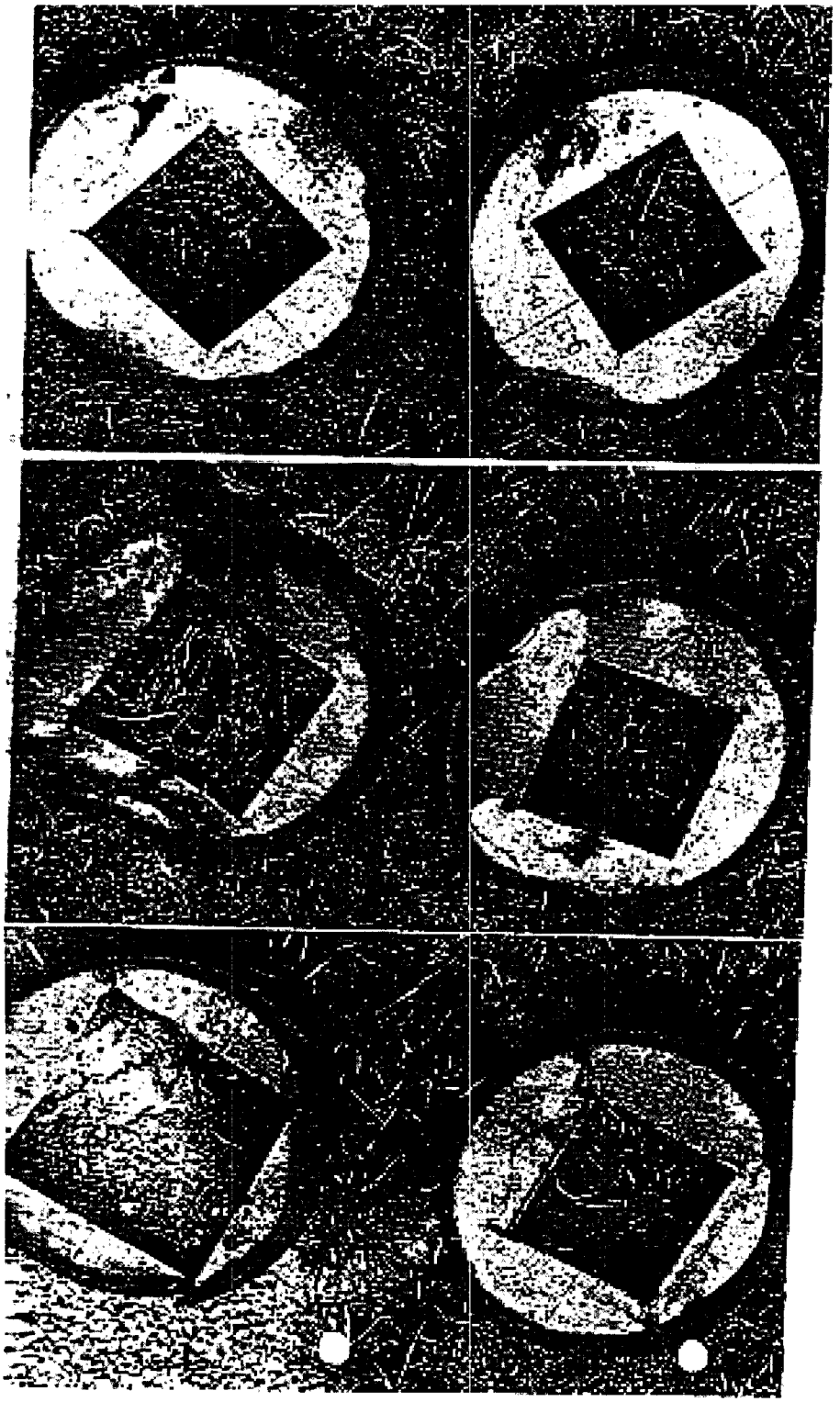
INNER CONTAINER - DRUM 009



FIBERBOARD RINGS - DRUM 009

FIBERBOARD RINGS - DRUM 009

FIBERBOARD RINGS - DRUM 009



FIBERBOARD RINGS - DRUM 009

FIBERBOARD RINGS - DRUM 009

FIBERBOARD RINGS - DRUM 009

3. SHIPPING CONTAINER QA PLAN

Our NRC-approved Shipping Container Quality Assurance Plan (dated 12-14-84) by the CNFP covers the design, fabrication, testing, inspection, use, and repair of radioactive materials shipping containers subject to the Q.A. requirements of 10 CFR 71.

This Plan was followed during the design of the DHTF and the procurement, construction, and testing of the prototypes. Further, this Plan will be applied to the procurement, fabrication, and inspection of additional DHTF packages, and to the use, routine inspection, repair, maintenance, and modification of additional DHTF packages.

4. CONTAINMENT

4.1 Containment Boundary

4.1.1 Containment Vessel

Within the DHTF container, the inner container assembly provides the containment boundary for the package contents. It comprises a welded stainless steel body and a thicker steel cover with a silicon rubber gasket.

4.1.2 Containment Penetrations

There are no penetrations into the primary containment.

4.1.3 Seals and Welds

A silicon rubber gasket compressed by the bolted-on cover seals the inner container. With a 1/8-inch thickness, the gasket forms a forgiving seal design in accommodating minor imperfections in the mating surfaces. Its performance is relatively unaffected at temperatures experienced during both normal transport and the hypothetical accident conditions as discussed in Sections 2.5. and 2.6.

Two angle sections are butt welded together with a longitudinal seam to form the container's square cross-section body. A bottom closure plate is butt-welded to the body. Welding, welder, and welding operator qualifications conform to the requirements prescribed by Section IX of the ASME Code. All welds are to be inspected with 7X magnification minimum.

4.1.4 Closure

A 3/8-inch-thick steel plate is used for the removable top cover on the inner container. It is attached to the perimeter flange of the main body by eight 3/8-inch bolts. All bolts and nuts are zinc-coated steel. An initial bolt torque of 35 lbs. ensures a positive seal during normal and accident conditions of transport.

4.2 Requirements for Normal Conditions of Transport

There will be no direct release of radioactive material from the containment vessel. This has been verified by the results from the pressurization test (Section 2.6.3). The inner container remained pressure tight when exposed to external pressures in the range of 3.5 psia to 20.0 psia. Visual inspection of a prototype package that had been subjected to a full series of drop tests indicated no degradation in effectiveness of the inner container or its silicon rubber gasket. No water in leakage was detected in the post-test examination.

4.3 Containment Requirements for the Hypothetical Accident Conditions:

Following the hypothetical accident conditions, the inner container must allow no loss or dispersal of radioactive contents. The outer drum may experience large deformations but the lid must remain attached. Local deformation and charring of the fiberboard is permitted.

Evaluation of the DHTF container for the hypothetical accident conditions required a series of tests performed in a pre-described sequence as described in Section 2.7. A post-test examination was performed on all six containers at the conclusion of the test series. A broad data base of experience has been accumulated on the performance of the DHTF container. In all cases, the containment boundary (inner vessel and seal) was intact with no significant deformations. In all cases, the containment system gasket was undamaged.

5. SHIELDING EVALUATION

Since the DHTF will contain low enriched (< 5.0 w/o) unirradiated uranium dioxide pellets, shielding concerns are minimal.

Since the DHTF is geometrically the same as the BW-2901, the radiation levels that have been historically seen on the BW-2901 can be used as a basis to describe the DHTF. A fully loaded DHTF will have four pellet boxes as opposed to the six boxes used in the BW-2901. Therefore it would be conservative to use the BW-2901 as a basis for the Health Physics evaluation of the DHTF.

A sampling of loaded BW-2901 containers are surveyed for each pellet receipt.

Radiation levels seen on BW-2901 containers loaded with four boxes of bagged UO2 scrap have all been < 2.0 mrem/hr. at contact. Radiation levels at 1 meter fall under 0.1 mrem/hr.

It is therefore consistent to conclude that the DHTF would meet the contamination and radiation limits as prescribed in 10 CFR 71 by virtue of the geometric and payload similarities to the BW-2901.

6. CRITICALITY EVALUATION

6.1 Discussion and Results

An analysis has been performed to determine the criticality safety of arrays of the DHTF shipping container at appropriate enrichments utilizing the packaging method for sintered UO2 pellets as described in drawings 1249874 and 1215600. Each container contains a maximum of 112 kg UO_2 (4 boxes with 28 kgs UO_2 per cardboard box) of fuel pellets (246.91 lbs. UO_2). The enrichment limit is variable depending on the content and configuration.

Two configurations were analyzed for shipment of solid pellets: pellet-tray and scrap. For the pellet-tray configuration four boxes of fuel are allowed per drum with an enrichment limit of 5.00 wt% U^{235} with pellet diameters ranging from 0.315" to 0.375" and fuel at 98% theoretical density (TD). For the scrap configuration, 4 boxes of fuel with pellet diameters (fragments) ranging from 0.2" to 0.375" have an enrichment limit of 3.85 wt% U^{235} with fuel at 98% TD. If three boxes of scrap plus one aluminum spacer are shipped, the enrichment limit is 5.00 wt% U^{235}.

In addition to solid pellet fuel, FCF intends to download fuel with and without an annulus and ship the pellets in the DHTF scrap configuration. The as-built fuel will not exceed 3.75 wt% U^{235}. The pellet diameter ranges from 0.296" to 0.300" with or without annuli ranging from 1.2 to 1.5 mm (0.0472" to 0.059"). The pellet diameter was conservatively evaluated at 0.28" since the smaller pellet diameter is shown to be most reactive. The fuel was evaluated with annuli ranging from 0.045" to 0.065" for conservatism. The enrichment limit of 3.75 wt% U^{235} for four boxes of fuel per drum was justified at 100% TD.

For the normal undamaged array an infinite number of undamaged packages are subcritical if stacked together in any arrangement. With NRC approval close water reflection has been conservatively bounded by the infinite array assumption.

For the Hypothetical Accident Conditions, a subcritical array size of 77 containers has been established for a Transportation Index of 1.3 for the DHTF container according to the revised regulations [1]. The TI of 1.3 allows shipment of 76 drums using an exclusive use vehicle. To maintain symmetry conditions in the array description 84 drums were evaluated. Therefore, the limiting TI is 1.3 based upon the Hypothetical Accident case results.

TABLE 6.1-1 - Summary of Limits for the DHTF Shipping Container (TI=1.3, 76 Containers Exclusive Use Vehicle)

Scrap Configuration Enrichment/No. of Boxes/ Theoretical UO_2 Density		Pellet-Tray Configuration Enrichment/No. of Boxes/ Theoretical UO_2 Density
Solid/Annular Fuel	Solid Pellet Fuel	Solid Pellet Fuel
3.75 wt%/4 Boxes/ 100% TD	3.85 wt%/4 Boxes/ 98% TD	5.00 wt%/4 Boxes/ 98% TD
5.00 wt%/3 boxes/ 100% TD	5.00 wt%/3 Boxes/ 98% TD	NA

The scrap configuration with four boxes of 0.2" diameter fuel pellets (which simulate broken pellets) in the scrap container represents the limiting package. This configuration is most limiting because the fuel pellets are assumed optimally moderated and contain no stainless-steel pellet trays (which act as neutron absorbers) in the scrap boxes. The scrap container assumes the presence of a maximum of 149 gms polyethylene per box. The total polyethylene limit per drum is 596 gms.

The dimensions important to criticality analysis are on drawing 1249874. The limiting cardboard dimensions are described on drawing 1215600. Table 6.1-2 lists the limiting dimensions obtained by working outward from the cardboard boxes.

Dimensions that minimize steel content will maximize K-effective since steel acts as a mild neutron absorber - especially stainless-steel 304 which contains nickel. Therefore, the drum wall thickness, the inner cavity wall, lid, cavity bottom, and the separator plate should use minimum thickness dimensions. The cane fiberboard acts as a shield to prevent neutron transfer between casks. The cane fiberboard consists primarily of cellulose. The cane fiberboard reduces neutron transmission between drums in an array. Therefore, the minimum drum height, minimum outer drum diameter (based on drop tests and fire tests), and maximum cavity dimensions were chosen to minimize fiberboard volume. The maximum internal cavity dimension also allows more water or optimized fuel (when it is broken out of the cardboard boxes) in the inner container. The inner steel cavity is assumed to have SS304 walls and bottom and a carbon steel lid. Carbon steel is more reactive than SS304 and if the drawing does not specify SS304 then carbon steel is assumed. A maximum internal cavity width of 9.625" square by 17.5" bounds any as-built dimensions of the internal cavity.

For cases when the cardboard box is assumed breached minimum cardboard box external dimensions are used to maximize the total fuel volume. The cardboard is assumed crushed to 0.06" (approximately 1/3 volume) for accident cases. For the single drum and normal array cases the maximum cardboard box dimensions are used to maximize the amount of fuel in the box (no fuel outside the boxes). The polyethylene liner in the cardboard boxes is 0.006" thick. The model also contains 137 grams of additional scrap polyethylene.

TABLE 6.1-2 - Dimension Tolerances (From Dwg. 02-1249874E Unless Noted)

Description	Drawing Value	Limiting Value
Steel plate insert SS304	9.125" min x 16.375" min x 0.437" min	9.125" x 16.375" x 0.437" min
Cardboard Box External Dimensions Dwg. 02-1215600D	4-1/4" x 9-1/8" x 8-1/4" ±3/16"	Accident Conditions 4.0625" x 8.9375" x 8.0625" min for Normal Conditions 4.4375" x 9.3125" x 8.4375" max
Inner Steel Cavity	17-1/4" ±1/4" x 9-1/2" ±1/8" sq.	17.5" x 9.625" (square) max
Bottom Steel Cavity SS304	1/4" ±1/16"	0.1875" min
Inner Steel Cavity Lid Carbon Steel or SS304 Flange is not modeled	3/8" ±1/16" x 12-3/4" ±1/8" sq.	0.3125" min x 9.743" max = (9-1/2"+1/8"+ 2(0.074" - 0.015"))
Outer Steel Cavity Dim SS304 (Except Lid) 14 gage	(17-1/4" ±1/4" +0.1875" min) x (9-1/2" ±1/8" +2(14 gauge ±0.015"))sq.	17.6875" max x 9.743" sq. max
Bottom Fiberboard Insert	6-1/2" min	6-1/2" min
Inside Drum Length	33-1/8" to 34"	33-1/8" min
Top Fiberboard Insert	Calculated 8.625" = (33.125" min - 6.5" min - 17.6875" max - 0.3125" min)	8.625" min
Cane Fiberboard Density	16.5 lbm/ft^3 ±2 lbm/ft^3	14.5 lbm/ft^3 min = 0.23227 g/cc min
Wood Diameter in Drum Fiberboard	22-1/2" OD ±1/8"	Normal Array 22.375" min Accident Array 21.06" min (Drop & Fire Test Results)
Drum O.D. (Less Ribs) Carbon Steel	22-1/2" ±1/8" + 2(16 gauge ±0.015")	Normal Array 22.463" min (22-1/2" -1/8" min +2(0.059" - 0.015" min)) Accident Array 21.148" min (21.06" + 2(0.059" - 0.015" min))
Drum Lip (Both Ends)	3/4" ±1/16 from ref inside drum dimension	0.6875" min -0.044" min = 0.6345"
Drum Top	16 gauge ±0.015"	0.044" min
Drum Bottom	16 gauge ±0.015"	0.044" min
Aluminum Spacer Document 32-1244648-00	4.25"±1/16" thick x 9.125" ±1/8" wide x 8.25" ±1/8" long	4.1875" x 9.0" x 8.125" min
Shipping Tray 1259101C-0	.0180" ± .0015" thick x 7.75" ± .02" wide x 8.70" ± .02" long	143.68 grams minimum tray weight

The drums were loaded into a close-packed hexagonal array three drums deep (28x3 array). All drums are assumed to be deformed by the maximum amount determined from drop-test results. All cardboard was assumed crushed to a minimum thickness of 0.06" to maximize fuel volume. The stainless-steel center separator plate has a minimum thickness of 0.437". Based on the analysis maximum reactivity occurs for the internal cavity fully flooded and all other regions in the drum and external to the drum dry.

Using this very conservative model, the final maximum K-effective with the bias (0.02 Δk) and uncertainty applied was determined for the different configurations (scrap and pellet-tray) at the appropriate limiting enrichment and theoretical fuel density. All final limiting cases satisfy the criticality limit of 0.95. The final results for different limiting configurations are shown in Table 6.1-3.

Both pellet and scrap package configurations are safe for shipment. These packaging configurations must conform to the descriptions and assumptions in this analysis. The Certificate of Compliance should contain the following specifications:

1) The maximum weight limit is 246.91 pounds (112 Kg) of UO_2 (4 boxes of fuel) with the U^{235} content not to exceed 4.83 kg U^{235} for the **pellet-tray** configuration. For the **scrap** configuration, the U^{235} content shall not exceed 3.72 kg U^{235}. For **scrap** annular fuel the content of U^{235} shall not exceed 3.55 kg. No annular fuel is allowed in the pellet-tray configuration.

   If the content of the drum is limited to 185.18 pounds (84 kg) of UO_2 (3 boxes of fuel) with the remaining space of one box occupied by an aluminum spacer the U^{235} content shall not exceed 3.62 kg U^{235} (5.00 wt% U^{235}) for solid pellet fuel in the scrap configuration or 3.55 kg U^{235} (5.00 wt% U^{235}) for annular pellet fuel.

2) The as-built enrichment limit will be 5.00 wt% U^{235} for 4 boxes of solid pellet fuel in the **pellet-tray** configuration. The as-built enrichment limit is 3.85 wt% U^{235} for 4 boxes of solid pellet fuel in the **scrap** configuration. The as-built enrichment limit is 3.75 wt% U^{235} for 4 boxes of fuel with or without an annulus.

   If one aluminum spacer replaces one of the boxes of fuel, 5.00 wt% U^{235} solid pellet fuel may be shipped in either the pellet-tray or scrap configurations. With one aluminum spacer 5.00 wt% U^{235} annular pellet fuel conforming to the previous description may be shipped in the scrap configuration. No annular fuel is allowed to be shipped in the pellet-tray configuration since this configuration was not analyzed.

3) The maximum allowed pellet density is 98.0% of the UO_2 theoretical density (10.96% x 0.98 = 10.7408 g/cc) for solid pellet fuel and 100% theoretical density for annular fuel.

4) A minimum pellet diameter of 0.315" and maximum pellet diameter of .375" applies for shipments utilizing trays. The annular fuel has a pellet diameter ranging from 0.291" to 0.304" (nominal is between 0.296" to 0.299") with or without an annulus. The fuel

annulus ranges between 1.14 - 1.65 mm (nominal is between 1.2 mm to 1.5 mm). Annular fuel may only be shipped in the scrap configuration.

5) The pellet trays should normally be fully loaded and the boxes may have up to 10 trays of pellets for larger diameter pellets and up to 12 trays for smaller diameter pellets. There is a criticality requirement that unoccupied space in the box contain stainless-steel trays or a volume displacement device since credit was taken for a minimum number (11) of the steel trays. The use of stainless-steel trays or spacers is required to prevent damage to pellets. The fuel trays in a box may have partial rows of pellets

6) For partial shipments with less than 4 boxes of fuel, the remaining space must be occupied with an aluminum block of equal or greater volume to prevent shifting of the fuel boxes and to occupy space.

7) The minimum dimensions of the stainless-steel 304 plate shall be 16.375" x 9.125" x 0.437". One plate shall be located between two rows of fuel boxes. See Figure 6.3-4.

8) The scrap and pellet-tray containers shall contain no more than 149 gms of polyethylene per box (596 grams total for 4 boxes).

9) The internal steel cavity of the drum shall not exceed 9.625" square by 17.5" in depth.

10) The cane fiberboard shall contain no asphalt.

TABLE 6.1-3 - DHTF Shipping Container Results

Condition	Model Configuration	K-maximum
Normal (Scrap)	Infinite Normal Array - 0.375" Dia. Solid Pellet, 4 Boxes, **5.00 wt%**, 100% TD	0.80858
Normal (Scrap-Annular)	Infinite Normal Array - 0.375"/0.146" Dia. Annular Pellet, 4 Boxes, **5.00 wt%**, 100% TD	0.76397
Accident (Scrap-Annular)	28X3 Hexagonal Array 0.28"/0.065" Dia. Annular Pellet, 4 Boxes, **3.75 wt%**, 100% TD	0.94893
Accident (Pellet-Tray)	28X3 Hexagonal Array 0.315" Dia. Solid Pellet, w/trays, 4 Boxes, **5.00 wt%**, 98% TD	0.94899
Single Flooded Drum (Scrap at 5.00 wt%)	Single Flooded Drum 0.200" Dia. Solid Pellet, 4 Boxes, **5.00 wt%**, 98% TD	0.79496
Single Flooded Drum (Scrap-Annular)	Single Flooded Drum 0.28"/0.065" Dia. Annular Pellet, 4 Boxes, **3.75 wt%**, 100% TD	0.75148

6.2 Package Fuel Loading

The DHTF shipping container drawings are contained in Section 1 of this document. The DHTF shipping container consists of a nominal 9.5" x 9.5" x 17-1/4" inch high inner container constructed with a minimum of 14-gauge (.0747 inches) stainless-steel (SS304). The top 3/8" inch thick steel flange (or lid) may be carbon steel or stainless steel 304 and is bolted and incorporates a gasket. The inner container is centered and supported in a 22.5 inch ID (smooth wall) x 34 inch high steel drum made of 16 gauge steel with a 16 gauge head. The inner container is supported and protected by cane fiberboard insulation material. FCF uses two different packaging arrangements with the container for the shipment of uranium dioxide fuel. These are described in the separate sections covering the evaluation of that packaging arrangement. Any packaging arrangements which vary from or alter the packages described below will require further evaluation. Table 6.2-1 describes the maximum fuel loadings and parameters for these loadings.

TABLE 6.2-1 - Package Fuel Loading

Material	Max Weight lbm/Kg UO_2 lbm/Kg U^{235}	Restrictions	Form
Fuel Pellets	246.91/112 10.65/4.83	Max Enrichment = 5.00 wt% U^{235} 4 Boxes Fuel, Pellet Diameters From 0.315"-0.375" No Annular Fuel, 596 gms Total Poly	UO_2 Pellets Pellet-Tray Configuration
Fuel Pellets	246.91/112 8.20/3.72	Max Enrichment = 3.85 wt% U^{235} 4 Boxes Fuel, No Annular Fuel, Scrap 596 gms Total Poly	UO_2 Pellets Scrap Configuration
Fuel Pellets	185.18/84 7.98/3.62	Max Enrichment = 5.00 wt% U^{235} 3 Boxes Fuel/1 Al Spacer, 447 gms Total Poly, No Annular Fuel Scrap	UO_2 Pellets Scrap Configuration 3 Boxes/1 Al Spacer
Fuel Pellets	237.36/107.66 7.67/3.48	Max Enrichment = 3.75 wt% U^{235} 4 Boxes Fuel, Solid or Annular Fuel, Scrap, 596 gms Total Poly	UO_2 Pellets Scrap Configuration Annular Fuel Only
Fuel Pellets	178.02/70.75 7.67/3.48	Max Enrichment = 5.00 wt% U^{235} 3 Boxes Fuel, Solid or Annular Fuel, Scrap, 447 gms Total Poly	UO_2 Pellets Scrap Configuration Annular Fuel Only 3 Boxes/1 Al Spacer

6.2.1 Stainless-Steel Plate Specification

The DHTF shipping container contains a single stainless-steel 304 plate which is used to separate two rows of fuel boxes (2 boxes in a row). The stainless-steel 304 plate must have minimum dimensions of 9.125" x 16.275" x 0.437". There is no additional absorbing material in the steel plate such as boron.

6.3 Model Specification

6.3.1 Description of Calculational Model

The analysis for both packagings was performed using the SCALE 4.2 package. CSAS2X calls BONAMI-S, NITWALII (to calculate the Dancoff correction factor), XSDRNPM-S (for flux and volume weighing of the cross-sections) and KENOVa. The 27 group cross-section library was used in all calculations.

The SCALE Package was prepared by the Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission and is widely used in criticality evaluations. The 27 group cross-section set was used because more accurate results have been obtained from benchmark calculations using Low-Enriched-Uranium (LEU) critical experiments. Additionally, the 27 group cross-section library eliminates any concerns pertaining to pre-treated U^{235} resonances associated with the 123 group cross-section set. A description of the bias is provided in Section 6.5.

The input data containing the atomic number densities and geometry are contained in the Section 6.6 appendix. The theoretical density was used in calculating the fuel atomic number densities. For annular pellet fuel 100% TD was assumed. For normal solid pellet fuel 98% TD was used. No credit was taken for dish or chamfer factors. The measured density of the cardboard was used in calculating atomic number densities for the single flooded and normal array cases. For the limiting hypothetical accident container calculations all cardboard was compressed to 1/3 of its normal volume and the composition of wood was assumed. Maximum cavity dimensions were assumed because this allows optimized fuel volume fractions and maximizes reactivity. For the accident configurations no credit is taken for the integrity of cardboard and fuel is assumed to break out of the boxes.

6.3.1.1 Criticality Models

Three models are used for the evaluation of the DHTF: normal array, single flooded, and accident configuration. Dimensioned sketches of the models used in the criticality evaluation are provided as Figures 6.3-1 through 6.3-6. Figure 6.3-1 shows a typical fuel pellet box and steel tray.

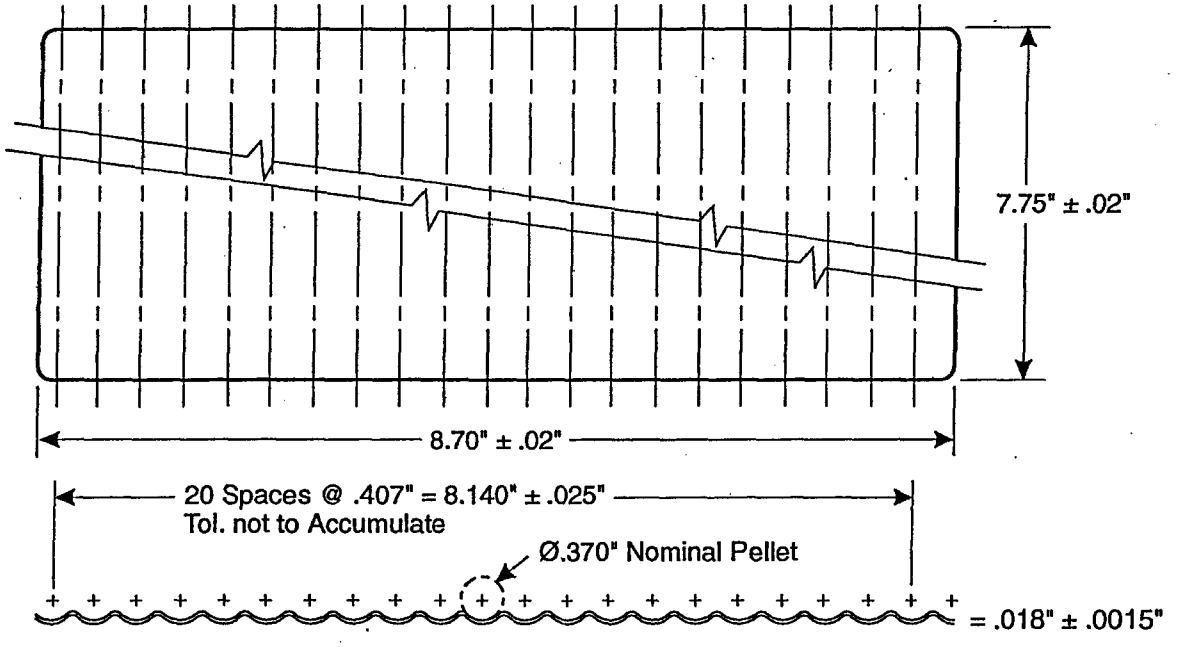
Figure 6.3-2 shows the geometry arrangement for fuel in the normally dry configuration. This model is reflected on all sides and represents an infinite array. The box detail is not shown and the reader is referred to Figure 6.3-4. For the infinite array model the container may contain either pellets in trays or scrap. For the pellet-tray model, the trays were not modeled.

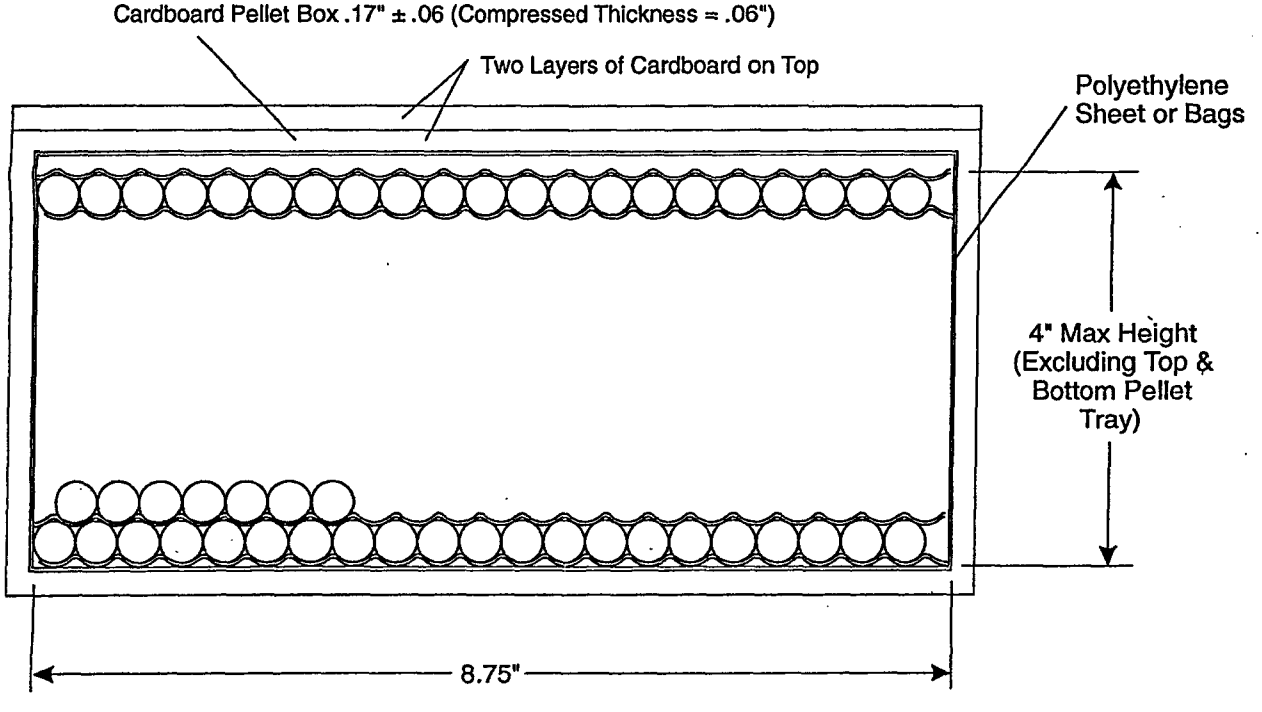
For the infinite scrap configuration additional polyethylene was added to the interior of each box. Note that for the infinite normal array cases that the drum is dry (non-moderated). Therefore, the largest K-effective occurs for the largest mass of fuel and the scrap configuration would not be limiting. However, the scrap model combined the heavy loading of the pellet-tray configuration with the additional polyethylene allowed in the scrap configuration to maximize K-effective.

Figure 6.3-3 describes the single flooded drum case which used optimized fuel for conservatism. For the single flooded drum case which is not considered an accident case, optimized scrap fuel is confined within the cardboard box with additional polyethylene. The cardboard box has maximum external dimensions to maximize the fuel volume inside. For this case, no credit is taken for the 4.0" maximum fuel thickness for conservatism. The drum is flooded externally and internally with fully dense water.

Figure 6.3-4 is an isometric view of the hypothetical accident array scrap case. The array size and orientation of the hypothetical accident case are shown in Figure 6.3-5. Figure 6.3-6 outlines the detail of the accident pellet-tray configuration which takes credit for 11 steel trays (minimum). Normally, the scrap configuration is more limiting than the pellet-tray configuration because it is not possible to achieve the reduced fuel volume fractions with that configuration. For conservatism, the pellet-tray model used in this analysis is the scrap model with 11 steel trays inserted and the fuel optimized for this configuration. The scrap polyethylene is maintained to maximize K-effective. This model provides a very conservative approximation of the pellet-tray configuration. For both the scrap and pellet-tray accident models, optimized fuel is added outside the cardboard boxes to fill all available volume in the inner cavity. For all accident cases, the drum diameter has been uniformly reduced (by both the drop test and fire test results) to maximize K-effective by reducing the amount of cane fiberboard insulation, the drum steel volume, and the tighter hexagonal pitch.

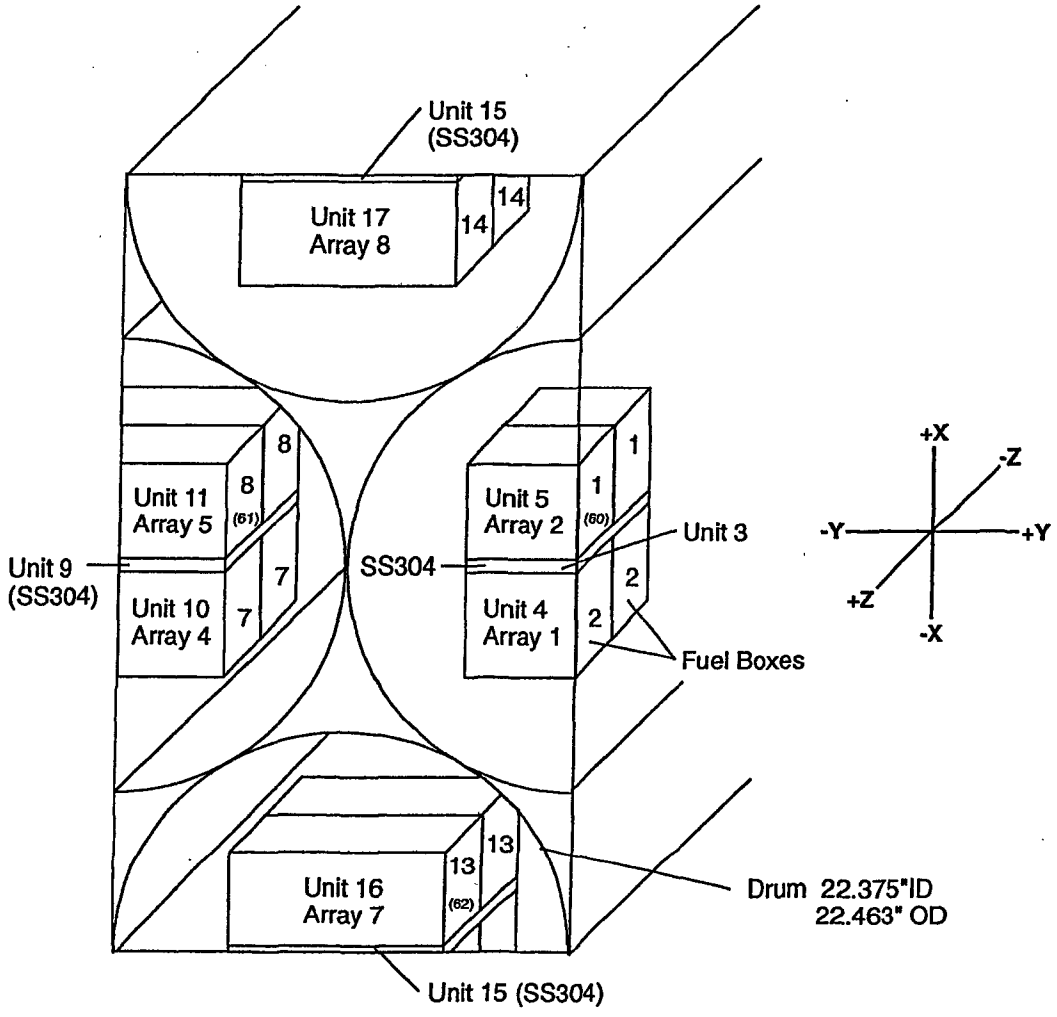
Figure 6.3-1
Box and Tray Dimensions





Nominal Box Size: 9 1/8 x 8 1/4 x 4 1/4 ± 3/16

Figure 6.3-2
Normal Infinite Array Pellet-tray and Scrap Model



1. Cardboard Box Dim. = 4.4375" x 9.3125" x 8.4375" (max)
2. Box Thickness [uncrushed = .11" (min)]
3. Fuel Occupies 4.0" (max) x 8.72" (max) x 7.77" (max)
4. Remaining Space is Void
5. No Steel Trays Modeled in Pellet-Tray Configuration
6. 137 gms Poly Added to Scrap Configuration
7. With No Moderator Largest Fuel Mass Is Most Conservative
8. Units 60, 61, and 62 Are Aluminum Spacer Blocks
9. See Figure 6.3-4 for General Box Detail
10. *Steel Cavity Detail Not Shown*

Figure 6.3-3
Single Flooded Drum
(Scrap Configuration)

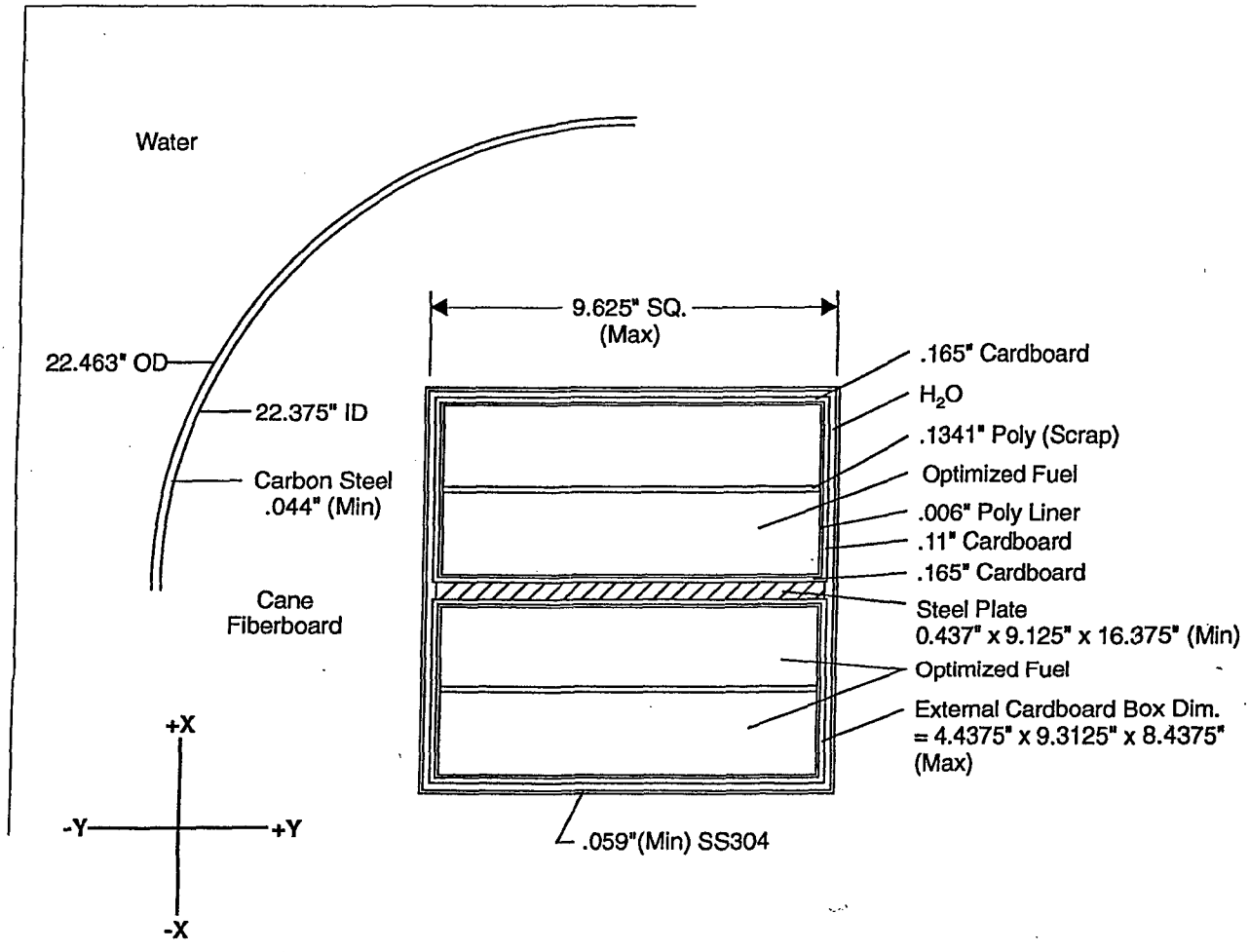


Figure 6.3-4
Hypothetical Accident Internal Cavity
(Scrap Configuration)

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 6.3-5
Hypothetical Accident Case Array Orientation (28x3)

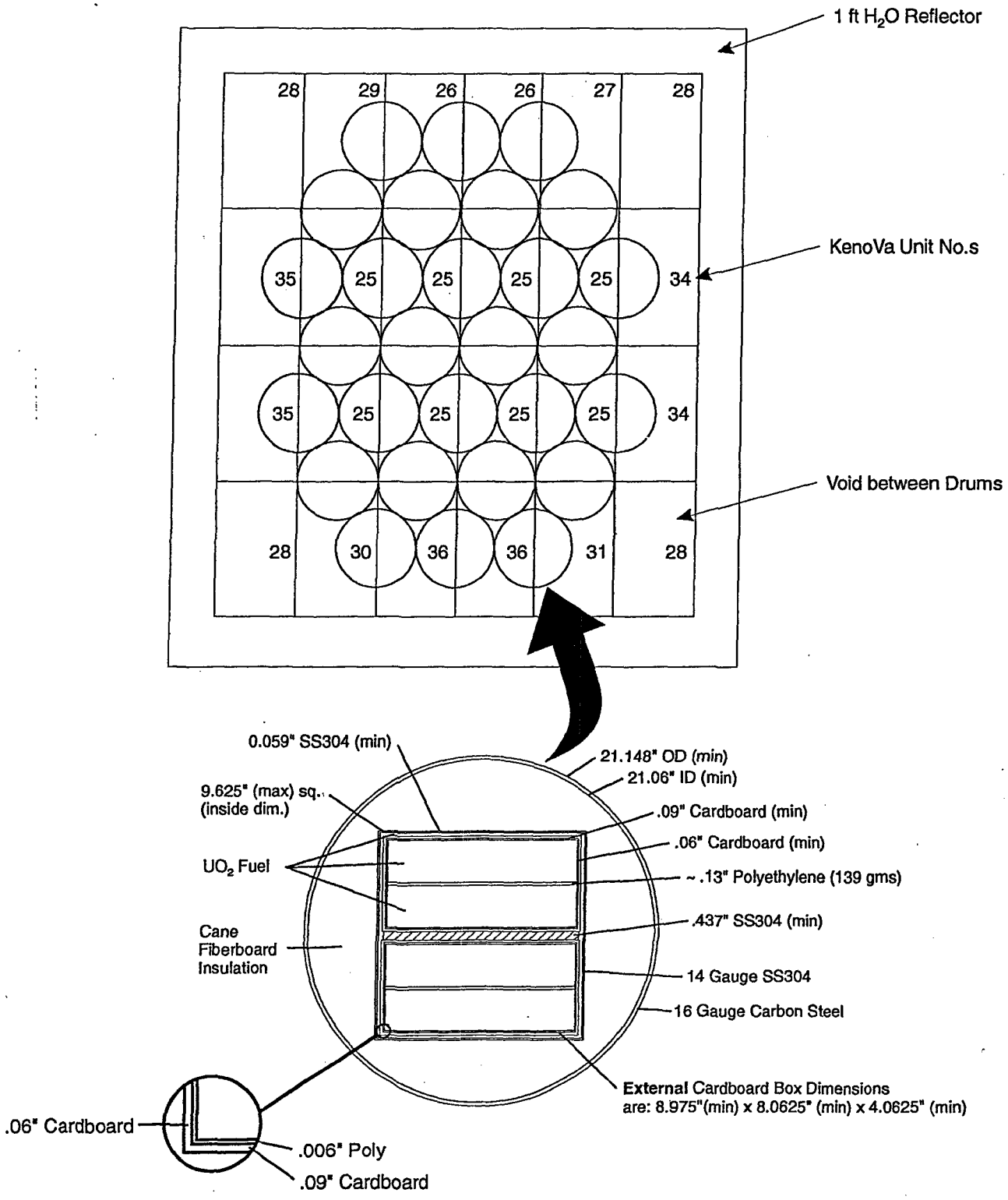
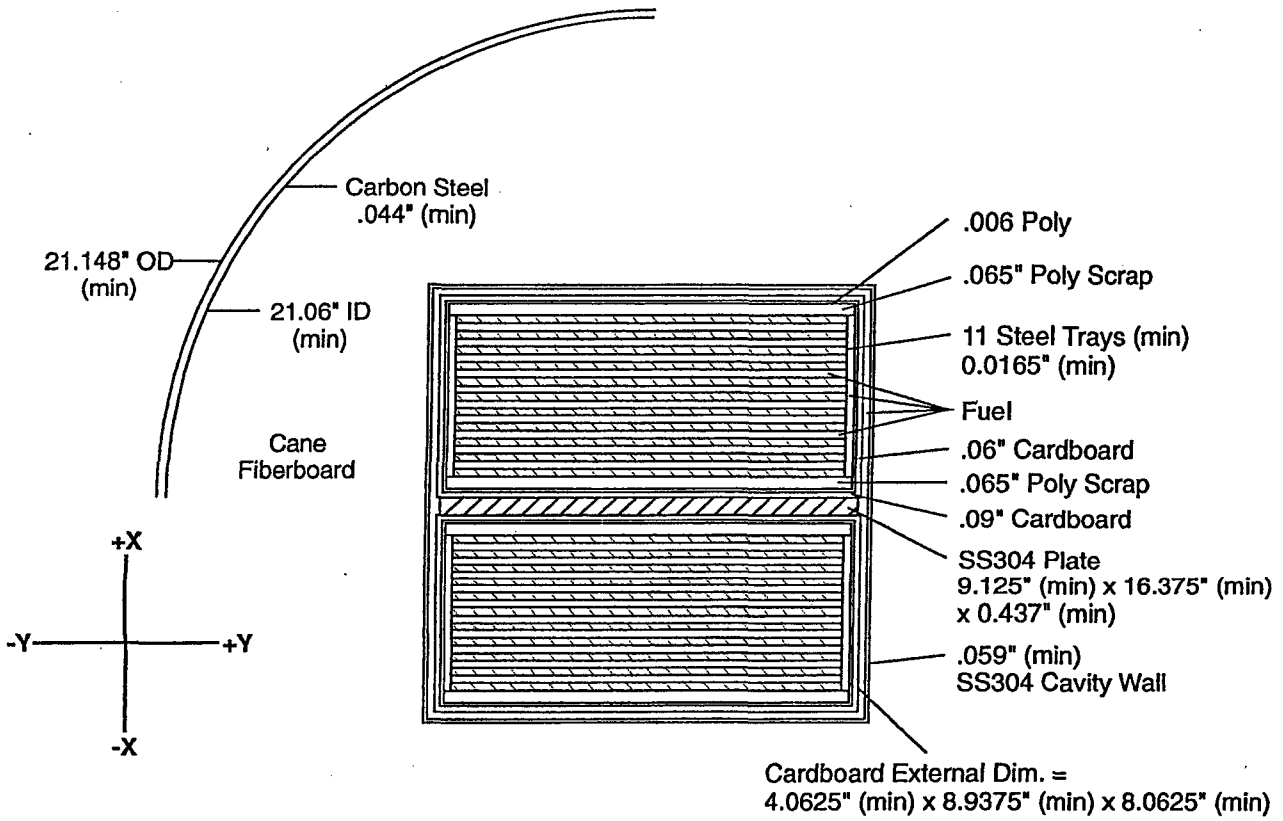


Figure 6.3-6
Hypothetical Accident Internal Cavity
(Pellet-Tray Configuration)



① Fuel occupies all regions inside & outside boxes

② Axial dimensions same as for scrap configuration

6.3.2 Package Regional Densities

The region densities and number densities for the various models are provided in Table 6.3.2-1. Table 6.3.2-1 lists various material values. Depending on the fuel configuration different enrichment limits and theoretical densities apply and a variety of fuel volume fractions were evaluated. Therefore, homogenized fuel and water densities are not provided in Table 6.3.2-1. The CSAS2X module does not require input in this form. The heterogeneous fuel densities for 5.00 wt% U^{235} are provided as an example.

TABLE 6.3.2-1 Material Number Densities

Material/Den	Element-Isotope	wt%	atom/b-cm
H_2O/ 1.0 g/cc	H O	11.1902 88.8098	6.68718-02 3.34359-02
Cane Fiberboard (Oak-Cellulose)/ 0.23227 g/cc	H C O	6.22 44.44 49.34	8.63140-03 5.17884-03 4.31570-03
Polyethylene/ 0.92 g/cc	H C	14.37 85.63	7.90600-02 3.95300-02
Carbon-Steel/ 7.8212 g/cc	Fe C	99.0 1.0	8.34982-02 3.92503-03
SS304/ 7.92 g/cc	Fe Cr Ni Mn	69.5 19.0 9.5 2.0	5.93579-02 1.74286-02 7.72074-03 1.73633-03
Normal Cardboard (Cellulose) 0.209 g/cc	H C O	6.22 44.44 49.34	7.82813-03 4.65998-03 3.88308-03
Compressed Cardboard (Hardwood) 0.6 g/cc	H C O	6.6247 53.1752 40.2001	2.37477-02 1.59965-02 9.07870-03
Aluminum 2.6989 g/cc	Al	100.0	6.02374-02
UO_2 5.00 wt% U^{235} in U/ 10.96 x 0.98 = 10.7408 g/cc	U^{235} U^{238} O	4.3543 83.7899 11.8558	1.21287-03 2.27534-02 4.79326-02

6.4 Criticality Calculation

6.4.1 Calculational Method

The revised criticality analysis was performed with the KENOVa Monte-Carlo code [2]. NITAWL-II processes the 27 group cross-section set to provide cross-sections for the analysis. Cell weighting calculations are performed by the XSDRNPM-S code for the fuel region. The SCALE 4.2 CSAS modules are used to automate the computation of resonance treated and cell weighted cross-sections and number density input. A series of benchmark cases for low enriched U^{235} arrays is described in Section 6.5. The bias from these cases is conservatively bounded by the 0.02 bias assumed in this analysis.

Box type geometry options were used in the analysis for normal and accident conditions of transport. Optimization of the fuel loading within the inner cavity and moderation between packages have been examined. Input listings for several bounding cases are provided in Section 6.6.

6.4.2 Fuel Loading Optimization

The analysis models both the pellet-tray and scrap configurations. The scrap container results with **equivalent** enrichments bound the pellet-tray configuration for the following reasons:

1) The fuel boxes contain stainless-steel trays which hold a specific number of pellets in an orderly array. The presence of the stainless-steel trays significantly reduces K-effective (about 2.6% Δk).

2) The pellet-tray fuel configuration allows higher loadings of uranium than the scrap container. Fuel redistributed within the internal cavity cannot achieve the optimum fuel volume fraction modeled in the scrap container and results in a significant decrease in K-effective.

The first packaging arrangement is for the shipment of fresh fuel pellets. The pellets are placed on 26 gauge (.0165" minimum thick) corrugated stainless steel trays. Each box contains either ten trays or twelve trays of pellets plus one extra tray on top (11 or 13 trays). The stack of trays is wrapped in 6 mil poly and the cardboard box (actual nominal thickness is 0.17"; minimum uncrushed thickness is 0.11"; crushed thickness is 0.06") is constructed around the stack. In the analysis the stack of boxes is created by placing a stainless-steel plate on two boxes of fuel followed by another two boxes of fuel. The combination of boxes is then strapped together before being placed within the inner steel cavity.

The tray of fuel pellets was modeled as alternating slabs of fuel and steel, each fuel slab containing an equal share of the fuel. The steel trays are conservatively modeled at the minimum thickness of 0.0165" and are assumed flat when they are actually corrugated.

This model underestimates the steel volume and overestimates the optimized fuel mass. In the accident scenarios any void spaces inside or outside of the cardboard boxes (but within the steel cavity) are filled with optimized fuel. Each box of fuel is individually modeled.

For the accident cases the minimum exterior cardboard dimensions are utilized since this approach minimizes the cardboard volume. Also, each layer of cardboard was crushed to 0.06" maximizing the space within the box. The pellet-tray configuration is similar to the scrap configuration described later except that the polyethylene is added to the top and bottom of the box due to the presence of the steel trays. Therefore, the pellet-tray configuration is basically the scrap configuration with steel trays added.

For the scrap container interspersed moderator conditions were evaluated and demonstrate that the worst moderator conditions exist with the internal cavity filled with fully dense water while all exterior regions outside the drums remain dry (except the 12" water reflector). These limiting moderator conditions determined for the scrap configuration were applied to the pellet-tray configuration. For the scrap pellet configuration up to 137 grams of polyethylene may be added to the box in addition to the polyethylene bag which is modeled as a liner. The scrap polyethylene is added to the center of the fuel mass in the box to maximize reactivity. Each box may contain no more than a total of 149 grams of polyethylene.

The inner container is modeled per FCF drawing 1249874. The analysis evaluated stainless-steel 304 for the sides and bottom of the containers using minimum thickness. The inner cavity lid may be either carbon steel or stainless-steel. Carbon steel was modeled because it is more reactive. Stainless-steel contains nickel which is a mild neutron absorber. The space between the inner container and the outer drum is filled with cane fiberboard to provide both insulation and a support structure for the inner cavity. The cane fiberboard contains no asphalt. For the accident condition, the inner diameter of the drum was reduced from 22.5 inches (nominal O.D.) to 21.06 inches (O.D.) based on the results of the drop tests and fire test results (see Chapter 2). The diameter of the cane fiberboard was reduced due to charring from the fire test with an average diameter of 21.4 inches for all drums tested. The absolute minimum of all drums fire tested was 21.06 inches and this diameter was used in all hypothetical accident cases. Note that the fire test was conducted after all drop tests had been performed and represents the minimum from all tests combined. All drop and fire tests were performed according to the requirements in the Federal regulations.

This is a conservative model because optimum moderation conditions were used, and the minimum theoretical density of 98% was used for UO_2 rather than the actual density (95-96% nominal theoretical density). The most reactive array shape was used - one with a shape factor as close to unity as possible. Also, the most restrictive fuel pellet pitch was that corresponding to optimized fuel.

The accident evaluation used the most reactive drum tolerances with an array size consistent with a Transportation Index (TI) of 1.3. The names of the computer runs and input decks are listed in subsequent tables for future identification.

6.4.2.1 Moderator Optimization

A moderation study was performed to determine the optimum amount of moderator both inside the inner container and outside of the inner container. The 4 box scrap configuration with the 0.20" diameter solid pellet, 3.85 wt% enrichment limit at 98% TD was chosen for this evaluation because it was the most restrictive typical scrap configuration calculated in Section 6.4.2 (see case 18 Table 6.4.2.5-1).

Table 6.4.2.1-1 demonstrates that the flooding of the inner container with the outer container somehow voided is the most reactive case, with a maximum k-effective of 0.94653. Use of this model adds conservatism since accidental flooding of the sealed inner container for all drums in an array with fuel suspended in an optimized state is so improbable as to be incredible.

Interspersed (low-water density) moderator cases were evaluated for water densities ranging from 1% up to 100% and with various combinations of water densities inside and outside the drums. The results are listed in Table 6.4.2.1-1. Cases 1-5 consider various degrees of moderation inside the drum with the external regions dry. These cases demonstrate that K-maximum is reached for 100% water density. Cases 6-9 evaluate the drums with the internal cavity fully flooded and the moderator conditions outside the drum varied from 3% to 100% density. These cases indicate that any moderator external to the drum reduces neutron transport between drums and results in a smaller value of K-maximum. Cases 10-14 have the same water densities inside and outside the drum and evaluate the low-water density range between 3%-10%, thus indicating that K-maximum increases monotonically to the 100% dense water case. Therefore, no secondary reactivity spikes were found at reduced water densities.

Variations in water densities inside and outside the drum are not expected to affect limiting annular fuel results since the reactivity margin is large for the solid pellet fuel results listed in Table 6.4.2.1-1. The internal cavity region fully flooded with 100% dense water and exterior regions dry has already been evaluated for annular fuel (see Table 6.4.2.7-1 Case 1). Water densities less dense than 100% inside the internal cavity (See Table 6.4.2.1-1 Cases 2-5) result in a decrease in K-maximum. Water densities outside the drum greater than zero result in a decrease in reactivity (Cases 6-9). Low water densities inside and outside the drum (Cases 10-14) are not limiting and there is a large amount of reactivity margin. Therefore, the limiting values of K-maximum are defined by the internal cavity fully flooded with 100% dense water and optimally moderated solid pellet fuel with dry exterior regions.

TABLE 6.4.2.1-1 - Interspersed Moderator Accident Cases
(3.85 wt%, 98% TD, 28x3 Array, 4 Boxes, Scrap, Solid Pellet Fuel)

Case No.	Pellet Dia./Type /VF/Microfiche/Inside-Outside Water Dens./Description	Base K-effective	1σ Unc	Maximum K-effective
1	0.20/ solid/ 0.31/b13723/ **100/0**; 20dhtf2acc3.85.31.98.in	0.92542	±0.00063	0.94653
2	0.20/ solid/ 0.31/b14341/ **50/0**; 20dhtf250.0.in	0.75765	±0.00061	0.77873
3	0.20/ solid/ 0.31/b14342/ **10/0**; 20dhtf210.0.in	0.60576	±0.00057	0.62676
4	0.20/ solid/ 0.31/b14343/ **5/0**; 20dhtf205.0.in	0.59369	±0.00054	0.61464
5	0.20/ solid/ 0.31/b14344/ **1/0**; 20dhtf201.0.in	0.58226	±0.00056	0.60325
6	0.20/ solid/ 0.31/b14345/ **100/3**; 20dhtf2100.3.in	0.92442	±0.00063	0.94553
7	0.20/ solid/ 0.31/b14364/ **100/5**; 20dhtf25.5.in	0.92318	±0.00066	0.94434
8	0.20/ solid/ 0.31/b14358/ **100/10**; 20dhtf2100.10.in	0.92036	±0.00065	0.94151
9	0.20/ solid/ 0.31/b14359/ **100/100**; 20dhtf2100.100.in	0.86566	±0.00063	0.88677
10	0.20/ solid/ 0.31/b14363/ **3/3**; 20dhtf23.3.in	0.59049	±0.00058	0.61151
11	0.20/ solid/ 0.31/b14501/ **4/4**; 20dhtf24.4.in	0.59279	±0.00055	0.61376
12	0.20/ solid/ 0.31/b14498/ **5/5**; 20dhtf25.5.in	0.59414	±0.00056	0.61513
13	0.20/ solid/ 0.31/b14508/ **6/6**; 20dhtf26.6.in	0.59679	±0.00057	0.61779
14	0.20/ solid/ 0.31/b14499/ **10/10**; 20dhtf210.10.in	0.60497	±0.00058	0.62599

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.2.2 Pellet Size Evaluation

Throughout the evaluation the effect of the pellet size was examined. Two sizes of solid pellets are used to bracket the range of pellet diameters normally used by CNFP. The fuel pellet diameters range between 0.32" and 0.37" OD. For conservatism and to account for pellet tolerances, diameters ranging from 0.315" to 0.375" are evaluated for scrap and pellet-tray configurations. For scrap configurations solid pellet diameters are evaluated down to 0.20" to represent pellet fragments. The specific annular fuel pellet design is also evaluated but only for the scrap configuration.

6.4.2.3 Normal Dry Array Cases

Normal drums are undamaged drums, with no other moderation except the normal amounts of polyethylene and cardboard, loaded with up to 112 kgs of UO_2 (4 boxes at 28 kgs per cardboard box at 98% TD), and have a minimum normal outer diameter of 22.375 inches.

For the normal pellet array cases which are dry, the greatest reactivity is expected for solid pellets in the pellet-tray configuration since this configuration results in the greatest total fuel mass. For conservatism the stainless-steel trays are ignored for this part of the DHTF analysis. The pellets are placed in a triangular pitch based upon the expected pitch for the pellet diameter. For the largest diameter pellets 10 trays of pellets can be loaded into a box while for the smallest diameter pellets (assumed to be 0.25" for these cases) the maximum is approximately 23 trays of pellets. Note that the maximum fuel thickness cannot exceed 4" due to plant fuel slab restrictions. The array of containers is assumed to be infinite for conservatism.

The stainless-steel trays are 0.018" $\pm$0.0015" thick. The minimum steel thickness is 0.0165". The nominal horizontal pitch between pellets in a tray is 0.407". Finding the altitude of a right triangle

$$(0.375" + 0.0165")^2 = (0.407"/2)^2 + X^2$$

$$X = 0.33445".$$

Dividing the 4.0" maximum by 0.33445" the maximum number of trays is 11.96 = 12 trays. In actuality only 10 trays of fuel are shipped for larger diameter pellets and 12 for smaller pellets (0.315") with one steel tray placed on the top row of pellets to protect them. The cardboard box volume must accommodate the polyethylene bag and a top and bottom stainless-steel tray.

In KENOVa, only equilateral triangle pitches can be modeled. Therefore, the effective pitch must be computed that maintains the same fuel to total volume ratio. The total area of the current "triangle" is 2 * 1/2ab = .407"/2*0.33445" = 0.06808 sq. in. For an equilateral triangle the pitch is P=(Area*4/sqrt(3))^{½}. For the area of 0.06808 sq. in., the pitch becomes **0.39651** in. For the infinite normal array this model is conservative because more water is added to the box volume than is allowed because the stainless-steel trays are not modeled. The 4.0" maximum fuel height is maintained while the tray dimensions of 8.70" ±0.02" and 7.75" ±0.02" define the maximum fuel dimensions in the other two directions as 8.72" and 7.77", respectively. Therefore, the homogenized fuel volume is placed in a fuel slab within each box with dimensions of **4.0" x 8.72" x 7.77"** for the pellet-tray configuration.

Using the same arguments previously described a smaller diameter pellet (0.25") has an altitude in the trays of

$$(0.25" + 0.0165")^2 = (0.407"/2)^2 + X^2$$

$$X = 0.172076"$$

The area of the triangle becomes 0.407/2*0.172076 = 0.035017 sq. in. For an equilateral triangle the pitch becomes P=(Area*4/sqrt(3))^{½}. The pitch for this case becomes **0.28438** in. Therefore, the normal array case is modeled with both pellet diameter extremes.

The results of the normal array evaluation is shown in Table 6.4.2.3-1. The cases in Table 6.4.2.3-1 considered pellet diameters ranging from **0.25" to 0.375"** and an arbitrary annulus equal to 15% of the largest diameter pellet for conservatism (0.375" x 0.15 = 0.146") even though this exceeds the annular fuel pellet description. Note that 0.20" diameter pellets were not evaluated because an equilateral triangle cannot be constructed using the previous method when the steel trays are inserted between the pellets because the resulting pitch will be smaller than the pellet diameter. Also, the 0.20" pellets represent pellet fragments and are not appropriate for the pellet-tray configuration. Note that discussions with the NRC indicated that it was not necessary to model a water reflector around the problem if infinite array conditions were assumed.

In addition to the pellet-tray configuration, a **scrap pellet configuration** is possible. The scrap model used the heavy mass loading characteristic of the pellet-tray model for conservatism except that 137 grams of additional polyethylene scrap were added to the interior of each box. The additional polyethylene is modeled in the middle of each cardboard box. This model is very conservative because it models much more fuel in a box than is possible

for scrap shipments and is conservative for dry (no water moderator) conditions.

The first five cases in Table 6.4.2.3-1 evaluated solid pellet fuel and demonstrate that the largest K-effective is generated for the configuration with the greatest amount of fuel (the largest diameter pellet) when there is no water moderator. Maximum K-effective occurs for the largest pellet diameter. If the pellet has an annulus, as in Case 6, fuel is removed and K-effective decreases. Therefore, annular fuel is not limiting relative to solid pellet fuel for the normal array cases. Also, the modified pellet-tray configuration (which bounds the scrap configuration) containing 137 grams polyethylene per box is more limiting than the regular pellet-tray configuration due to the polyethylene moderator. Therefore, the largest value of K-maximum was calculated for the 0.375" diameter solid pellet with 137 grams additional polyethylene. K-maximum **was computed to be 0.80858 and provides a large amount of reactivity margin to the criticality limit.**

TABLE 6.4.2.3-1 - Infinite Dry Container Array
5.00 wt% U^{235} 100% TD, Density H2O=0.0, Normal Array

Case No.	Pellet Dia./ Annulus /VF/ Microfiche/ Description	Base K-effective	1σ Unc	Maximum K-effective
1	0.25/ solid/ 0.70/ b11205/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray**, 25dhtf.70pt.in	0.74492	±0.00054	0.76588
2	0.315/ solid/ 0.73/ b12583/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray** 32dhtf.73pt.in	0.74842	±0.00059	0.76946
3	0.375/ solid/ 0.81/ b11208/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray** 37dhtf.81pt.in	0.75730	±0.00056	0.77829
4	0.25/ solid/ 0.70/ b14594/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray (Scrap) w/Poly**, 25dhtf.70sp.in	0.77761	±0.00056	0.79860
5	0.375/ solid/ 0.81/ b14520/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray (Scrap) w/Poly** 37dhtf.81sp.in	0.78763	±0.00054	0.80858
6	0.375/0.146/ 0.688/ b11385/ Fuel mass restricted to 4.0"x8.72"x7.77" Vol, **Pellet-Tray** 3714dhtf.68.in	0.74300	±0.00055	0.76397

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.2.4 Single Flooded Container

Calculations are required for a single drum with optimized fuel in the normal non-accident configuration fully flooded. For this representative example of cases it was determined that the scrap configuration was most reactive. Therefore, several cases at various fuel volume fractions and pellet diameters were evaluated. The single flooded cases differ from the scrap accident calculations in a later section in the following ways:

1) Only a single drum is evaluated versus an array.

2) The single drum case is not considered an accident case so optimized fuel is confined within the cardboard boxes.

3) Maximum cardboard box external dimensions were utilized to maximize the volume of optimized fuel within the box.

4) All regions inside and outside the drum are flooded with fully dense water.

5) At least two feet of water are added to regions exterior to the drum to ensure adequate neutron reflection and drum isolation.

Examination of the single flooded drum cases in Table 6.4.2.4-1 reveal that K-maximum is less than 0.80 for all cases with either the solid pellet fuel or downloaded annular fuel. The 4 box scrap configuration was evaluated because it was more limiting than the pellet-tray configuration. The enrichments were defined by the limiting accident array cases in sections 6.4.2.5 and 6.4.2.6.

Cases 1-4 evaluate the 0.20" diameter pellet in the scrap configuration with 137 gms of additional polyethylene per box. These results indicate an optimum volume fraction in the range of 0.26-0.31 with 0.26 the calculated maximum. Because K-maximum is so low further searches for the optimum was deemed unnecessary. Cases 5-8 evaluate the 0.315" diameter pellet while Cases 9-13 evaluate the 0.375" diameter pellet. The optimum volume fractions were calculated for the different pellet diameters to be 0.28 and 0.30, respectively. The annular fuel was also evaluated in Cases 14-17 and the optimum fuel volume fraction occurred at 0.28.

To ensure 5.0 wt% U^{235} fuel is acceptable three additional cases are evaluated. One evaluated 3 boxes of fuel (case 18) and two evaluated four boxes of fuel (cases 19 and 20) in the scrap configuration. With three boxes of fuel the volume fraction of 0.26 was chosen. The four box cases evaluate volume fractions of 0.26 and 0.31. The results of these cases demonstrate acceptable results. Therefore, single flooded drums are not limiting and provide significant reactivity margin to the 0.95 criterion.

TABLE 6.4.2.4-1 - Single Flooded Container
(Scrap Configuration, Density H2O=100.0)

Case No.	Pellet Dia./ Annulus /VF/ Microfiche/ Description	Base K-effective	1σ Unc	Maximum K-effective
1	0.20/ solid/ 0.26/ b15407/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf3.85.26.in	0.73040	±0.00065	0.75155
2	0.20/ solid/ 0.28/ b15100/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf3.85.28.in	0.72986	±0.00066	0.75102
3	0.20/ solid/ 0.30/ b15102/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf3.85.30.in	0.72859	±0.00067	0.74977
4	0.20/ solid/ 0.31/ b15104/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf3.85.31.in	0.72634	±0.00067	0.74752
5	0.315/ solid/ 0.28/ b15409/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 32dhtf3.85.28.in	0.72864	±0.00065	0.74979
6	0.315/ solid/ 0.31/ b15108/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 32dhtf3.85.31.in	0.72728	±0.00066	0.74844
7	0.315/ solid/ 0.32/ b15110/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 32dhtf3.85.32.in	0.72506	±0.00067	0.74624
8	0.315/ solid/ 0.33/ b15112/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 32dhtf3.85.33.in	0.72426	±0.00067	0.74544
9	0.375/ solid/ 0.28/ b15411/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 37dhtf3.85.28.in	0.72553	±0.00065	0.74668
10	0.375/ solid/ 0.30/ b15412/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 37dhtf3.85.30.in	0.72618	±0.00062	0.74727
11	0.375/ solid/ 0.33/ b15113/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 37dhtf3.85.33.in	0.72403	±0.00065	0.74518
12	0.375/ solid/ 0.34/ b15114/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 37dhtf3.85.34.in	0.72222	±0.00069	0.74344
13	0.375/ solid/ 0.35/ b15115/ 3.85 wt%, 4 Boxes, 98% T.D. Fuel, 37dhtf3.85.35.in	0.72066	±0.00063	0.74177
14	0.28/0.065 annular/ 0.28/ b15417/ 3.75 wt%, 4 Boxes, 100% T.D. Fuel, 28dhtf3.75.28.in	0.73037	±0.00063	0.75148
15	0.28/0.065 annular/ 0.30/ b15119/ 3.75 wt%, 4 Boxes, 100% T.D. Fuel, 28dhtf3.75.30.in	0.72929	±0.00063	0.75040

Case No.	Pellet Dia./ Annulus /VF/ Microfiche/ Description	Base K-effective	1σ Unc	Maximum K-effective
16	0.28/0.065 annular/ 0.31/ b15120/ 3.75 wt%, 4 Boxes, 100% T.D. Fuel, 28dhtf3.75.31.in	0.72883	±0.00067	0.75001
17	0.28/0.065 annular/ 0.32/ b15122/ 3.75 wt%, 4 Boxes, 100% T.D. Fuel, 28dhtf3.75.32.in	0.72702	±0.00066	0.74818
18	0.20/ solid/ 0.26/ b15445/ 5.00 wt%, 3 Boxes, 98% T.D. Fuel, 20dhtf5.00.26.al.in	0.70164	±0.00068	0.72284
19	0.20/ solid/ 0.31/ b15480/ 5.00 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf5.00.31.in	0.76586	±0.00069	0.78708
20	0.20/ solid/ 0.26/ b15511/ 5.00 wt%, 4 Boxes, 98% T.D. Fuel, 20dhtf5.00.26.in	0.77369	±0.00072	0.79496

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.2.5 Limiting Hypothetical Accident Scrap Array Cases

For the accident array the minimum array size must be computed based upon the Transportation Index (TI) and the desired number of containers to be shipped. For transportation by exclusive use vehicles the number of drums to be shipped times the transport index must be ≤ 100 (see 10CFR Part 71.59.(c).(1) - April 1996 Amendment). For shipping 76 containers the TI is computed as follows:

TI = 100/76 = 1.3 (rounded downward)

The minimum array size is computed as:

2*N = min. to evaluate = 100/TI;

where N is rounded up to the nearest whole number.

N= 100/1.3 = 76.92 = 77 drums in the array to be evaluated.

To check this let 2*N = 77; N = 38.5

50/38.5 = 1.2987 (round up to 1.3)

1.3 * 76 = 98.8 which is <100.

The array size actually evaluated has 84 drums based upon symmetry conditions but only 76 drums can be shipped at a time.

The annular downloaded fuel in the scrap configuration is evaluated first. The fuel consists of a pellet diameter that ranges from 0.296" to 0.300". The annulus ranges from 1.2 - 1.5 mm (0.0472" to 0.0591"). For the DHTF shipping container the peak reactivity occurs for the smallest diameter pellet with the greatest annulus diameter. Therefore, the optimization study performed for the DHTF evaluated a 0.28" diameter pellet with a 0.065" diameter annulus to bound any tolerances on the nominal pellet dimensions. Case 1 in Table 6.4.2.5-1 demonstrates that criticality criterion is exceeded at 5.00 wt% U^{235} with 4 boxes of scrap pellet annular fuel. If one aluminum block is added to the container so that there are only 3 boxes of fuel (Case 2) the criticality criterion is satisfied. Cases 3-10 are run for fuel volume fractions spanning 0.27 - 0.34. The optimum fuel volume fraction was found to occur in the range of 0.31 - 0.33. To verify that the peak occurs with the largest annulus the annulus was reduced to 0.045" and the pellet diameter maintained at 0.28". Case 11 demonstrates that the larger annulus pellet is most reactive as expected. Note that Cases 3-11 were evaluated for 3.75 wt% U^{235} and represents a bounding as-built enrichment for the fuel (about 3.70 wt% is the actual maximum).

Case 12 examines the 0.20" diameter pellet fragment at 5.00 wt% U^{235} with 4 boxes of fuel and demonstrates criticality criterion is exceeded. When one box of fuel is removed as before, 5.00 wt% U^{235} scrap is acceptable (Case 13). Cases 14 - 20 demonstrate that the optimum fuel volume fraction occurs between 0.29 - 0.32 with 0.31 the calculated maximum for a 0.20" diameter pellet at 3.85 wt% U^{235}. **Note the solid pellet cases in this table are at 100% TD and the theoretical density was subsequently reduced to 98% in the final limiting cases.** The uncertainty on K-effective makes definition of the precise volume fraction difficult. However, the difference in K-maximum over this range is very small.

Cases 21 - 28 evaluate the 0.315" diameter pellet at 3.85 wt% U^{235} while Cases 29 - 35 evaluate the maximum 0.375" diameter pellet at the same enrichment. For the 0.315" diameter pellet the optimum volume fraction occurs between 0.32 - 0.33 with the calculated maximum K-effective at 0.32. For the 0.375" diameter pellet the optimum fuel volume fraction occurs between 0.33 - 0.35 with the calculated maximum at 0.33.

The results in Table 6.4.2.5-1 which are all run at 100% TD are used to help define the limiting array scrap cases discussed later in Table 6.4.2.7-1.

TABLE 6.4.2.5-1 - Accident Scrap Container Arrays (28x3 Array, 100% TD, Dens H2O=1.0, Scrap)

Case No.	Pellet Dia./ Type /VF/ Enrich/ Microfiche/ Description	Base K-effective	1σ	Maximum K-effective
1	0.28/ 0.065/ 0.28/ 5.00 b12456/ 4 Boxes; **Annular;** 2806dhtf2acc.in	0.98196	±0.00066	1.00312
2	0.28/ 0.065/ 0.28/ 5.00 b15716/ 3 Boxes and 1 Al spacer; **Annular;** 2806dhtf2accal.in	0.91372	±0.00067	0.93490
3	0.28/ 0.065/ 0.27/ 3.75 b12500/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.27.in	0.92015	±0.00063	0.94126
4	0.28/ 0.065/ 0.28/ 3.75 b12460/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.in	0.92303	±0.00060	0.94409
5	0.28/ 0.065/ 0.29/ 3.75 b12505/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.29.in	0.92451	±0.00064	0.94564
6	0.28/ 0.065/ 0.30/ 3.75 b12543/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.30.in	0.92661	±0.00063	0.94772
7	0.28/ 0.065/ 0.31/ 3.75 b12713/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.31.in	0.92615	±0.00064	0.94728
8	0.28/ 0.065/ 0.32/ 3.75 b15660/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.32.in	0.92728	±0.00063	0.94839
9	0.28/ 0.065/ 0.33/ 3.75 b15743/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.33.in	0.92785	±0.00061	0.94893
10	0.28/ 0.065/ 0.34/ 3.75 b15781/ 4 Boxes; **Annular;** 2806dhtf2acc3.75.34.in	0.92656	±0.00061	0.94764
11	0.28/ 0.045/ 0.28/ 3.75 b12499/ 4 Boxes; **Annular;** 2804dhtf2acc3.75.in	0.92060	±0.00058	0.94162
12	0.20/ solid/ 0.28/ 5.00 b12468/ 4 Boxes; **Solid;** 20dhtf2acc.in	0.97897	±0.00064	1.00010
13	0.20/ solid/ 0.28/ 5.00 b15717/ 3 Boxes 1 Al spacer; **Solid;** 20dhtf2accal.in	0.91108	±0.00067	0.93226
14	0.20/ solid/ 0.27/ 3.85 b12494/ 4 Boxes; **Solid;** 20dhtf2acc3.85.27.in	0.92484	±0.00063	0.94595
15	0.20/ solid/ 0.28/ 3.85 b12465/ 4 Boxes; **Solid;** 20dhtf2acc3.85.in	0.92667	±0.00065	0.94782
16	0.20/ solid/ 0.29/ 3.85 b12491/ 4 Boxes; **Solid;** 20dhtf2acc3.85.29.in	0.92789	±0.00064	0.94902

Case No.	Pellet Dia./ Type /VF/ Enrich/ Microfiche/ Description	Base K-effective	1σ	Maximum K-effective
17	0.20/ solid/ 0.30/ 3.85 b12544/ 4 Boxes; Solid; 20dhtf2acc3.85.30.in	0.92739	±0.00062	0.94848
18	0.20/ solid/ 0.31/ 3.85 b12716/ 4 Boxes; Solid; 20dhtf2acc3.85.31.in	0.92906	±0.00063	0.95017
19	0.20/ solid/ 0.32/ 3.85 b13497/ 4 Boxes; Solid; 20dhtf2acc3.85.32.in	0.92736	±0.00064	0.94849
20	0.20/ solid/ 0.33/ 3.85 b13518/ 4 Boxes; Solid; 20dhtf2acc3.85.33.in	0.92721	±0.00065	0.94836
21	0.315/ solid/ 0.27/ 3.85 b12516/ 4 Boxes; Solid; 32dhtf2acc3.85.27.in	0.91947	±0.00065	0.94062
22	0.315/ solid/ 0.28/ 3.85 b12513/ 4 Boxes; Solid; 32dhtf2acc3.85.in	0.92187	±0.00062	0.94296
23	0.315/ solid/ 0.29/ 3.85 b12515/ 4 Boxes; Solid; 32dhtf2acc3.85.29.in	0.92308	±0.00061	0.94416
24	0.315/ solid/ 0.30/ 3.85 b12545/ 4 Boxes; Solid; 32dhtf2acc3.85.30.in	0.92626	±0.00063	0.94737
25	0.315/ solid/ 0.31/ 3.85 b12717/ 4 Boxes; Solid; 32dhtf2acc3.85.31.in	0.92670	±0.00064	0.94783
26	0.315/ solid/ 0.32/ 3.85 b13499/ 4 Boxes; Solid; 32dhtf2acc3.85.32.in	0.92870	±0.00063	0.94981
27	0.315/ solid/ 0.33/ 3.85 b13519/ 4 Boxes; Solid; 32dhtf2acc3.85.33.in	0.92829	±0.00062	0.94938
28	0.315/ solid/ 0.34/ 3.85 b13689/ 4 Boxes; Solid; 32dhtf2acc3.85.34.in	0.92729	±0.00061	0.94837
29	0.375/ solid/ 0.29/ 3.85 b12707/ 4 Boxes; Solid; 37dhtf2acc3.85.29.in	0.92184	±0.00065	0.94299
30	0.375/ solid/ 0.30/ 3.85 b12708/ 4 Boxes; Solid; 37dhtf2acc3.85.30.in	0.92291	±0.00061	0.94399
31	0.375/ solid/ 0.31/ 3.85 b12709/ 4 Boxes; Solid; 37dhtf2acc3.85.31.in	0.92561	±0.00062	0.94670
32	0.375/ solid/ 0.32/ 3.85 b12546/ 4 Boxes; Solid; 37dhtf2acc3.85.32.in	0.92512	±0.00064	0.94625
33	0.375/ solid/ 0.33/ 3.85 b13520/ 4 Boxes; Solid; 37dhtf2acc3.85.33.in	0.92775	±0.00065	0.94890

Case No.	Pellet Dia./ Type /VF/ Enrich/ Microfiche/ Description	Base K-effective	1σ	Maximum K-effective
34	0.375/ solid/ 0.34/ 3.85 b13691/ 4 Boxes; Solid; 37dhtf2acc3.85.34.in	0.92685	±0.00066	0.94801
35	0.375/ solid/ 0.35/ 3.85 b13692/ 4 Boxes; Solid; 37dhtf2acc3.85.35.in	0.92734	±0.00064	0.94847

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.2.6 Pellet-Tray Shipment Evaluation

The pellet-tray configuration is similar to the scrap configuration with the exception that a maximum of 11 steel trays are included in each box of fuel and the pellets are arranged in an orderly array with much higher fuel volume fractions. The steel trays are a mild neutron absorber and they displace optimized fuel. Only 11 trays are considered since this is the minimum number required for a full box of pellets with 0.375" diameter pellets. Smaller diameter pellets would require more trays so it is conservative to assume only 11 are present. Additionally the trays are modeled as slabs when in reality they are serpentine in design. Therefore, the total volume of steel is conservatively underestimated. Partially full boxes are not limiting because the remaining space in the box must be filled with steel trays which displace more fuel mass and adds more absorber to the cavity.

The pellet-trays are assumed flat with a minimum thickness of 0.0165" and a minimum length and width of 7.73" and 8.68", respectively. The alternating layers of steel and optimized fuel are centered within each of the cardboard boxes. This model is very conservative because optimized fuel occupies all remaining regions inside and outside of the fuel boxes. All cardboard volume is minimized and assumed crushed as before.

Table 6.4.2.6-1 shows the pellet-tray accident cases. Case 1 is evaluated with 4 boxes of fuel and a pellet diameter of 0.315". The UO_2 fuel density was assumed to be a maximum of 98% T.D. The maximum enrichment of 5.00 wt% U^{235} was chosen. Volume fractions of fuel were varied from 0.32 to 0.38 in Cases 1-6 to determine the optimum volume fraction. The calculated optimum volume fraction was determined to be 0.36 with K-maximum of 0.94899.

Fuel pellets with a diameter of 0.375" were also evaluated and shown to be slightly less limiting than the smaller diameter pellets. Cases 7-12 evaluate optimum fuel volume fractions of 0.33 to 0.38. The calculated optimum volume fraction was 0.36 with a K-maximum of 0.94790. Note that pellet

diameters smaller than 0.315" are not evaluated because pellet fragments are not relevant for the pellet-tray configuration. Also note that the box contains 137 grams of additional polyethylene and is a conservative model because it duplicates the scrap configuration with the exception of steel trays. Each bag used to wrap the fuel pellets weighs approximately 50 grams. Even if double bagging were used 137 grams would bound any polyethylene added inside or outside the cardboard box. There are often additional cardboard liners added to the boxes to protect the fuel pellets which would displace optimized fuel. These liners are not modeled since their use is optional.

TABLE 6.4.2.6-1 - Accident Pellet-Tray Container Arrays
(28x3 Array, 5.00 wt% U^{235}, 98% TD, Dens H2O=1.0)

Case No.	Pellet Dia./ Type /VF/ Enrich/ Microfiche/ Description	Base K-effective	1σ	Maximum K-effective
1	0.315/ solid/ 0.32/ 5.00 b15606/4 Boxes; **Solid;** 32dhtfptst5.00.32.in	0.92707	±0.00063	0.94818
2	0.315/ solid/ 0.33/ 5.00 b15602/4 Boxes; **Solid;** 32dhtfptst5.00.33.in	0.92609	±0.00061	0.94717
3	0.315/ solid/ 0.34/ 5.00 b15568/4 Boxes; **Solid;** 32dhtfptst5.00.34.in	0.92737	±0.00060	0.94843
4	0.315/ solid/ 0.36/ 5.00 b15605/4 Boxes; **Solid;** 32dhtfptst5.00.36.in	0.92793	±0.00060	0.94899
5	0.315/ solid/ 0.37/ 5.00 b15680/4 Boxes; **Solid;** 32dhtfptst5.00.37.in	0.92567	±0.00065	0.94682
6	0.315/ solid/ 0.38/ 5.00 b15612/4 Boxes; **Solid;** 32dhtfptst5.00.38.in	0.92538	±0.00064	0.94651
7	0.375/ solid/ 0.33/ 5.00 b15609/4 Boxes; **Solid;** 37dhtfptst5.00.33.in	0.92366	±0.00062	0.94475
8	0.375/ solid/ 0.34/ 5.00 b15610/4 Boxes; **Solid;** 37dhtfptst5.00.34.in	0.92443	±0.00061	0.94551
9	0.375/ solid/ 0.35/ 5.00 b15611/4 Boxes; **Solid;** 37dhtfptst5.00.35.in	0.92552	±0.00065	0.94667
10	0.375/ solid/ 0.36/ 5.00 b15631/4 Boxes; **Solid;** 37dhtfptst5.00.36.in	0.92677	±0.00064	0.94790
11	0.375/ solid/ 0.37/ 5.00 b15681/4 Boxes; **Solid;** 37dhtfptst5.00.37.in	0.92644	±0.00062	0.94753
12	0.375/ solid/ 0.38/ 5.00 b15623/4 Boxes; **Solid;** 37dhtfptst5.00.38.in	0.92464	±0.00063	0.94575

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.2.7 Limiting Accident Arrays

Limiting accident array cases are shown in Table 6.4.2.7-1. These cases are evaluated at or near the optimum fuel volume fractions identified in Tables 6.4.2.5-1 and 6.4.2.6-1 using **98% T.D.** fuel except for annular fuel which

assumes 100% T.D. fuel. In some cases minor shifts in the optimum were noted with increased fuel enrichment. Case 1 evaluates the limiting annular fuel and demonstrates that the **3.75 wt%** enrichment limit is acceptable for the annular pellet design using 4 boxes of scrap fuel. Cases 2 - 4 evaluate 0.20", 0.315", and 0.375" solid pellet fuel at **3.85 wt% U^{235}** and indicate that criticality criterion is satisfied with 4 boxes of **scrap** fuel. Cases 5 - 6 evaluate the **pellet-tray** configuration and demonstrate that a **5.00 wt% U^{235}** enrichment limit is acceptable with 4 boxes of fuel.

Case 7 evaluates 3 boxes of annular fuel at 5.00 wt% U^{235} and 100% T.D. and demonstrates that K-maximum is less than 0.95. Likewise, Cases 8 - 10 indicate that 3 boxes of pellets in the scrap configuration at 5.00 wt% U^{235} are acceptable.

TABLE 6.4.2.7-1 - Limiting Accident Cases

Case No.	Pellet Dia./ Type /VF/ Enrich/ Microfiche/ Description	Base K-effective	1σ Unc	Maximum K-effective
1	0.28/ 0.065/ 0.33/ 3.75 b15743/4 Boxes; Annular Fuel; 100% TD Fuel, Scrap 2806dhtf2acc3.75.33.in	0.92785	±0.00061	0.94893
2	0.20/ solid/ 0.31/ 3.85 b13723/4 Boxes; Solid Fuel; 98% TD Fuel, Scrap 20dhtf2acc3.85.31.98.in	0.92542	±0.00063	0.94653
3	0.315/ solid/ 0.32/ 3.85 b13728/4 Boxes; Solid Fuel; 98% TD Fuel, Scrap 32dhtf2acc3.85.32.98.in	0.92581	±0.00064	0.94694
4	0.375/ solid/ 0.33/ 3.85 b13734/4 Boxes; Solid Fuel; 98% TD Fuel, Scrap 37dhtf2acc3.85.33.98.in	0.92367	±0.00062	0.94476
5	0.315/ solid/ 0.36/ 5.00 b15605/4 Boxes; Solid Fuel; 98% TD Fuel, Pellet-Tray 32dhtfptst5.00.36.in	0.92793	±0.00060	0.94899
6	0.375/ solid/ 0.36/ 5.00 b15631/4 Boxes; Solid Fuel; 98% TD Fuel, Pellet-Tray 37dhtfptst5.00.36.in	0.92677	±0.00064	0.94790
7	0.28/ 0.065/ 0.32/ 5.00 b15757/3 Boxes; Annular Fuel; 100% TD Fuel, Scrap 2806dhtf2acc3b5.00.32.in	0.91567	±0.00066	0.93683
8	0.20/ solid/ 0.31/ 5.00 b15758/3 Boxes; Solid Fuel; 98% TD Fuel, Scrap 20dhtf2acc3b5.00.31:98.in	0.91029	±0.00066	0.93145
9	0.315/ solid/ 0.32/ 5.00 b15759/3 Boxes; Solid Fuel; 98% TD Fuel, Scrap 32dhtf2acc3b5.00.32.98.in	0.90798	±0.00068	0.92918
10	0.375/ solid/ 0.33/ 5.00 b15760/3 Boxes; Solid Fuel; 98% TD Fuel, Scrap 37dhtf2acc3b5.00.33.98.in	0.90533	±0.00065	0.92648

The maximum K-effective is calculated as $K_{max} = K_{BASE} + BIAS + 1.763*(UNC_{BASE})$, where the total UNC factor is the 1.763σ value and the BIAS = 0.02.

6.4.3 Criticality Results

The most limiting results of the criticality safety analysis for the DHTF shipping container analysis are summarized in Table 6.4.3-1. These cases represent the worst cases calculated for different pellet diameters for the normal array, single flooded drum, and hypothetical accident array. Solid pellets and annular fuel are differentiated. The maximum K-effective values were computed from the following formula:

$$K\text{-maximum} = K\text{-effective} + Bias + 1.763\sigma.$$

where K-effective is calculated by KENOVa, σ is the uncertainty in the KENOVa calculation, and, the Bias is 0.02 as described in Section 6.5.

With the number of active generations equal to 847 (first 3 generations are skipped) a one-sided upper tolerance factor of 1.763 is justified. The limiting values of K-maximum are reported for the limiting and bounding container cases. The results provided in Table 6.4.3-1 and the conservative assumptions used in the various models ensure that the DHTF shipping container satisfies criticality safety requirements.

TABLE 6.4.3-1 - DHTF Shipping Container Results

Condition	Model Configuration	K-maximum
Normal (Pellet-Tray)	Infinite Normal Array - 0.25" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 100% TD	0.76588
Normal (Scrap)	Infinite Normal Array - 0.25" Dia. Solid Pellet, 4 Boxes, 5.00 wt%, 100% TD, w/ Poly	0.79860
Normal (Scrap-Annular)	Infinite Normal Array - 0.25" Dia. Annular Pellet, 4 Boxes, 5.00 wt%, 100% TD	Not Calculated (0.375" Diameter Limiting}
Normal (Pellet-Tray)	Infinite Normal Array - 0.315" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 100% TD	0.76946
Normal (Scrap)	Infinite Normal Array - 0.315" Dia. Solid Pellet, 4 Boxes, 5.00 wt%, 100% TD	Not Calculated (0.375" Diameter Limiting}
Normal (Scrap-Annular)	Infinite Normal Array - 0.315" Dia. Annular Pellet, 4 Boxes, 5.00 wt%, 100% TD	NA (Annular Fuel Only)
Normal (Pellet-Tray)	Infinite Normal Array - 0.375" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 100% TD	0.77829
Normal (Scrap)	Infinite Normal Array - 0.375" Dia. Solid Pellet, 4 Boxes, 5.00 wt%, 100% TD, w/poly	0.80858
Normal (Scrap-Annular)	Infinite Normal Array - 0.375"/0.146" Dia. Annular Pellet, 4 Boxes, 5.00 wt%, 100% TD	0.76397 (Dimensions and Enrichment bound Annular fuel)
Accident (Pellet-Tray)	28X3 Hexagonal Array 0.200" Dia. Solid Pellet, w/trays, 4 Boxes, 5.00 wt%, 98% TD	NA (Diameter too small for Pellet-Tray)
Accident (Scrap)	28X3 Hexagonal Array 0.200" Dia. Solid Pellet, 4 Boxes, 3.85 wt%, 98% TD	0.94653
Accident (Scrap-Annular)	28X3 Hexagonal Array 0.28"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	0.94893
Accident (Pellet-Tray)	28X3 Hexagonal Array 0.315" Dia. Solid Pellet, w/trays, 4 Boxes, 5.00 wt%, 98% TD	0.94899
Accident (Scrap)	28X3 Hexagonal Array 0.315" Dia. Solid Pellet, 4 Boxes, 3.85 wt%, 98% TD	0.94694
Accident (Scrap-Annular)	28X3 Hexagonal Array 0.315"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	NA (Annular Fuel Diameter Only)
Accident (Pellet-Tray)	28X3 Hexagonal Array 0.375" Dia. Solid Pellet, w/trays, 4 Boxes, 5.00 wt%, 98% TD	0.94790
Accident (Scrap)	28X3 Hexagonal Array 0.375" Dia. Solid Pellet, 4 Boxes, 3.85 wt%, 98% TD	0.94476

Condition	Model Configuration	K-maximum
Accident (Scrap-Annular)	28X3 Hexagonal Array 0.375"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	NA (Annular Fuel Diameter Only)
Single Flooded Drum (Pellet-Tray)	Single Flooded Drum 0.200" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 98% TD	Not Calculated (Scrap Most Limiting at 5.00 wt%)
Single Flooded Drum (Scrap at 5.00 wt%)	Single Flooded Drum 0.200" Dia. Solid Pellet, 4 Boxes, 5.00 wt%, 98% TD	0.79496
Single Flooded Drum (Scrap-Annular)	Single Flooded Drum 0.28"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	0.75148
Single Flooded Drum (Pellet-Tray)	Single Flooded Drum 0.315" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 98% TD	Not Calculated (Scrap Most Limiting)
Single Flooded Drum (Scrap)	Single Flooded Drum 0.315" Dia. Solid Pellet, 4 Boxes, 3.85 wt%, 98% TD	0.74979
Single Flooded Drum (Scrap-Annular)	Single Flooded Drum 0.315"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	NA (Annular Fuel Diameter Only)
Single Flooded Drum (Pellet-Tray)	Single Flooded Drum 0.375" Dia. Solid Pellet, 4 Boxes, no trays, 5.00 wt%, 98% TD	Not Calculated (Scrap Most Limiting)
Single Flooded Drum (Scrap)	Single Flooded Drum 0.375" Dia. Solid Pellet, 4 Boxes, 3.85 wt%, 98% TD	0.74727
Single Flooded Drum (Scrap-Annular)	Single Flooded Drum 0.375"/0.065" Dia. Annular Pellet, 4 Boxes, 3.75 wt%, 100% TD	NA (Annular Fuel Diameter Only)

6.5 Critical Benchmark Experiments

6.5.1 Benchmark Experiments and Applicability

Twenty-one Lynchburg Research Center (LRC) critical experiments were examined to quantify the KENOVa bias using both KENO-IV and KENOVa results for low-enriched uranium systems. The experiments involved three dimensional arrays of uranium fuel rods with intervening regions of either water, borated isolation sheets, or B_4C pins.

The 21 LRC critical configurations were chosen for the benchmark calculations and have the following similarities to the container configuration:

1) low-enriched systems,
2) interspersed hydrogenous moderator,
3) borated aluminum isolation sheets,
4) fissile material size and shape.

Thus, the criticality experiments chosen for the benchmark calculations are directly applicable for this analysis.

6.5.2 Details of the Benchmark Calculations

The approach to defining an applicable bias is to perform benchmark calculations using the KENO-IV code with the 27 group cross-section library. Since KENOVa was used in the analysis of the DHTF, comparison cases were run between KENO-IV and KENOVa which demonstrate excellent agreement between both KENO versions. It was necessary to use KENOVa in the DHTF analysis for several reasons:

1) The detailed geometry of the inner cavity would be very difficult to model using KENO-IV and KENO-IV does not allow modeling of a hexagonal array,

2) Use of the CSAS modules reduces the chance of errors in the treatment of resonance absorbers and in the preparation of number density input,

3) KENOVa allows treatment of P_3 scattering cross-section components. The use of the FCF KENO-IV code will only allow P_1 scattering and cases performed at FCF indicate that some SCALE 4.2 KENOVa results may have K-effective results that are 0.005 Δk higher than with KENO-IV. Therefore, use of the SCALE4.2 library with KENOVa is conservative relative to other available KENO versions at FCF.

6.5.2.1 LRC Critical Benchmark Results

The 21 critical LRC benchmark calculations were evaluated using the 27 group SCALE 4.2 cross-section library in Reference 2. The KENO-IV calculations in Table 6.5.2.1-1 were performed using 625 neutrons per generation and 600 generations. The first 102 generations were skipped yielding a total of 311,250 neutron histories. Examination of Table 6.5.2.1-1 results indicates that the SCALE 27 group cross-section library with the CSASN (BONAMI-S/NITAWL-II) cross-section treatment results in a maximum non-conservative bias of -0.01429 $\pm$0.00148 for core IX.

To test the adequacy of the neutron density per generation, core VI was rerun with a total of 850 generations and 2000 neutrons per generation. This case results in k-effective of 0.99781 $\pm$0.00053 with only the first 3 generations skipped. This case is shown in Table 6.5.2.1-2 along with other core VI results and indicates that larger neutron densities and generations are required to obtain meaningful results and statistics.

Table 6.5.2.1-3 shows the calculated bias for the **eight most limiting** core configurations identified from Table 6.5.2.1-1 using 2000 neutrons/generation and 847 generations. The maximum calculated bias with uncertainty was -0.01335 $\pm$0.00197 for core XVI and represents a core with a water gap of

1.288 inches with borated aluminum isolation sheets in the water gap region. With the exception of core I and IX the other cases contained B_4C pins or borated aluminum isolation sheets. There is **no statistically significant trend** of the bias with separation distance or intervening materials. Therefore, the same 27 group bias and uncertainty is used for all problem types represented by these critical configurations.

TABLE 6.5.2.1-1 - KENO-IV LRC Critical Results With CSASN 27 Group Library (Neutrons per Generation = 625; Number of Active Generations = 498)

Spacing Between Arrays (in.)	Core Number	KENOIV On IBM 6000 w/ CSASN/27 Gp (1 σ Uncertainty)	Measured (1 σ Unc)	Calculated Minus Measured (1 σ Uncertainty)
None	I	0.98903 (0.00127)	1.0002 (0.0005)	-0.01117 (0.00136)
	II	1.00489 (0.00104)	1.0001 (0.0005)	+0.00479 (0.00115)
0.644	III	1.00438 (0.00099)	1.0000 (0.0006)	+0.00438 (0.00116)
	IV	0.98764 (0.00120)	0.9999 (0.0006)	-0.01226 (0.00134)
	XI	1.00013 (0.00108)	1.0000 (0.0006)	+0.00013 (0.00124)
	XIII	0.99377 (0.00120)	1.0000 (0.0010)	-0.00623 (0.00156)
	XIV	0.99323 (0.00115)	1.0001 (0.0010)	-0.00687 (0.00152)
	XV	0.99266 (0.00106)	0.9998 (0.0016)	-0.00712 (0.00192)
	XVII	0.99619 (0.00113)	1.0000 (0.0010)	-0.00381 (0.00151)
	XIX	1.00027 (0.00099)	1.0002 (0.0010)	+0.00007 (0.00141)
1.288	V	0.98603 (0.00117)	1.0000 (0.0007)	-0.01397 (0.00136)
	VI	0.99602 (0.00109)	1.0097 (0.0012)	-0.01368 (0.00162)
	XII	0.99439 (0.00116)	1.0000 (0.0007)	-0.00561 (0.00135)
	XVI	0.98777 (0.00121)	1.0001 (0.0019)	-0.01233 (0.00225)
	XVIII	0.99390 (0.00112)	1.0002 (0.0011)	-0.00630 (0.00157)
	XX	0.99767 (0.00113)	1.0003 (0.0011)	-0.00263 (0.00157)
1.932	VII	0.98589 (0.00116)	0.9998 (0.0009)	-0.01391 (0.00147)
	VIII	1.01234 (0.00123)	1.0083 (0.0012)	+0.00404 (0.00172)
	X	0.99469 (0.00119)	1.0001 (0.0009)	-0.00541 (0.00149)
	XXI	0.98649 (0.00117)	0.9997 (0.0015)	-0.01321 (0.00190)
2.576	IX	0.98871 (0.00118)	1.0030 (0.0009)	-0.01429 (0.00148)

TABLE 6.5.2.1-2 - KENO-IV LRC Core VI Results Using Variable Generations and Densities With CSASN 27 Group Library

Gen. Skipped	Act Gen/ Hist.	KENOIV On IBM 6000 w/ CSASN/27Gp (1σ Uncertainty)	Measured (1σ Unc)	Calculated Minus Measured
3	212/625	0.99322 (0.00189)	1.0097 (0.0012)	-0.01648
102	498/625	0.99602 (0.00109)	1.0097 (0.0012)	-0.01368
3	297/1000	0.99625 (0.00126)	1.0097 (0.0012)	-0.01345
102	198/1000	0.99806 (0.00149)	1.0097 (0.0012)	-0.01164
3	847/2000	0.99781 (0.00053)	1.0097 (0.0012)	-0.01189
102	748/2000	0.99736 (0.00056)	1.0097 (0.0012)	-0.01234

TABLE 6.5.2.1-3 - KENO-IV LRC Critical Results Using CSASN 27 Group Library For Worst Eight Core Configurations
(Neutrons per Generation = 2000;
Number of Active Generations = 847)

Spacing Between Arrays (in.)	Core Number	KENO-IV On IBM 6000 w/ CSASN/27Gp (1σ Uncertainty)	Measured (1σ Unc)	Calculated Minus Measured (1σ Uncertainty)
None	I	0.98964 (0.00053)	1.0002 (0.0005)	-0.01056 (0.00073)
0.644	IV	0.98892 (0.00052)	0.9999 (0.0006)	-0.01098 (0.00079)
1.288	V	0.98797 (0.00052)	1.0000 (0.0007)	-0.01203 (0.00087)
	VI	0.99715 (0.00049)	1.0097 (0.0012)	-0.01255 (0.00130)
	XVI	0.98675 (0.00051)	1.0001 (0.0019)	-0.01335 (0.00197)
1.932	VII	0.98689 (0.00050)	0.9998 (0.0009)	-0.01291 (0.00103)
	XXI	0.98896 (0.00050)	0.9997 (0.0015)	-0.01074 (0.00158)
2.576	IX	0.99100 (0.00051)	1.0030 (0.0009)	-0.01200 (0.00103)

6.5.2.2 Statistically Calculated Maximum Bias

The previous calculations defined the maximum 27 group bias plus uncertainty from using the worst single core configuration. A more precise understanding of the bias is to view it in a statistical sense. It is possible that any single measured or calculated core configuration could have included larger errors than those that would actually occur if the experiment were repeated. To state the case another way, is it appropriate to penalize all future criticality results because one of twenty-one core configurations appears to indicate a larger bias which could be the result of random measurement error? This type of problem is addressed in statistical analysis by considering the determination of the expected sample mean and is a valid approach to use when groups of calculations are done at different conditions (as is the case for the different core configurations). The sample mean approach would view the core critical experiments as separate entities. If each core configuration experiment (and KENO-IV analysis) were repeated a very large number of times, all core configurations would converge on the true sample mean. Furthermore, the true sample mean would be the same for each of the experiments. The true or expected sample mean is defined as:

$$E(x) = \sum_{i=1}^{i=M} w_i x_i / \sum_{i=1}^{i=M} w_i$$

where w_i and $_ix$ are the weighting factors and the core bias values, respectively. E(x) is the expected sample mean. The weighting factors are defined as:

$$w_i = n_i / \sigma_i^2$$

where n_i and σ_i are the number of KENO-IV generations (sample size) and the combined measured and KENO-IV calculated standard deviation, respectively.

The expected sample mean of the bias was conservatively computed to be -0.01159 using only the **worst eight core configurations** while for comparison the average bias of the eight worst core configurations was computed to be -0.01189. Both values are very close. The standard deviation for the expected sample mean method is the maximum standard deviation computed for any individual core. In this case the 1σ value is ± 0.00197 from core XVI. The one-sided upper tolerance factor at the 95/95 confidence level is assumed to be the same as for the KENO-IV results or 1.763. For the average bias method the standard deviation is computed directly from the

worst eight core configurations to be ±0.0009093 with a one-sided upper tolerance factor at the 95/95 confidence level of 3.188. To summarize; the expected sample mean method results in a bias of **-0.01159 ±0.00347 (1.763σ)**. The average bias method results in a bias of **-0.01189 ±0.00290 (3.188σ)**. **For this analysis a bias of 0.02 was used (with no uncertainty) to conservatively bound any reasonable expected bias, to eliminate any NRC concerns over bias trends with separation distance, and to be consistent with the original licensed analysis.**

6.5.2.3 Benchmark Comparisons Using KENO-IV and KENOVa

Benchmark cases were run for the container using both the 123 group and the 27 group cross-section libraries using the SCALE4.2 code package. These benchmark cases were originally evaluated for the BW2901 pellet shipping container in Reference 3. The CSAS2X module was used which uses the BONAMI-S/NITAWL-II/XSDRNPM-S/KENOVa code sequence. Since, the Reference 3 analysis used the 123 group library with KENO-IV, a benchmark case was run with KENOVa for comparison.

The most limiting case identified in the Reference 3 benchmark analysis was for a 6x6x4 accident array of containers with the center region of the drum filled with water and uranium scrap and all external regions of the drum (and outside the drums) were void. A 2σ uncertainty and 0.02 bias was maintained as in the original analysis.

TABLE 6.5.2.3-1 - Benchmark K-effectives For The 6x6x4 Accident Array

Enrich./ Microfiche	Base K-eff.	2σ Unc.	Max. K-eff.	Description
5.1 wt%/ Reference Base Case	0.912	±0.007	0.939	Reference - Base case
5.1 wt%/ b11825	0.91131	±0.00120	0.93251	27 gp Base case w/KENOVa
5.1 wt%/ b11850	0.91173	±0.00118	0.93291	123 gp Base case w/KENOVa

Table 6.5.2.3-1 results indicate that the 27 group and 123 group base K-effective results agree quite well with the base accident calculation results (compare original license base case, b11825 and b11850). K-maximum

values were different because the reanalysis considered 847 active generations with 2000 neutrons per generation. Therefore, the total number of neutron histories is many more than the referenced base accident case.

6.5.3 Results of Benchmark Calculations

The results of the benchmark calculations and the KENOVa comparison cases suggest that a KENOVa bias of **0.01159 ± 0.00347 (1.763σ)** is justifiable. **However, to ensure conservatism of the bias with KENOVa the original SAR bias of 0.02 was maintained.** The use of this bias implies 0.005 Δk conservatism.

6.6 Appendix - Calculations

This section provides a list of number densities used in the final limiting calculations along with KENOVa input deck listings.

6.6.1 Number Densities

The number densities used in the final limiting calculations for the scrap container are provided because these calculations bound all earlier generation analyses. Homogeneous fuel densities are not provided because the CSAS2X module computes these values automatically and internally transmits the homogenized densities to KENOVa via fuel material 500. Also, a potentially, large number of number densities are computed for the fuel volume fraction studies. Shown in Table 6.6.1-1 is a listing of important number density information.

TABLE 6.6.1-1 - Material Number Densities

Material/Den	Element-Isotope	wt%	atom/b-cm [A]
H_2O/ 1.0 g/cc	H O	11.1902 88.8098	6.68718-02 3.34359-02
Cane Fiberboard (Oak-Cellulose)/ 0.23227 g/cc	H C O	6.22 44.44 49.34	8.63140-03 5.17884-03 4.31570-03
Polyethylene/ 0.92 g/cc	H C	14.37 85.63	7.90600-02 3.95300-02
Carbon-Steel/ 7.8212 g/cc	Fe C	99.0 1.0	8.34982-02 3.92503-03
SS304/ 7.92 g/cc	Fe Cr Ni Mn	69.5 19.0 9.5 2.0	5.93579-02 1.74286-02 7.72074-03 1.73633-03
Normal Cardboard (Cellulose) 0.209 g/cc	H C O	6.22 44.44 49.34	7.82813-03 4.65998-03 3.88308-03
Compressed Cardboard (Hardwood) 0.6 g/cc	H C O	6.6247 53.1752 40.2001	2.37477-02 1.59965-02 9.07870-03
Aluminum 2.6989 g/cc	Al	100.0	6.02374-02
UO_2 5.00 wt% U^{235} in U/ 10.96 x 0.98 = 10.7408 g/cc	U^{235} U^{238} O	4.3543 83.7899 11.8558	1.21287-03 2.27534-02 4.79326-02

[A] Avagadro's number = 0.6022138 x 10^{24} atoms/gaw.

6.6.2 Selected Input File Listings

This section contains a listing of the input decks that represent the limiting cases performed in the analyses according to pellet type and configuration. The values of K-maximum for these cases are shown in Table 6.1-3. A more complete listing of all limiting cases by configuration, accident classification, and pellet type is shown in Table 6.4.3-1. Representative cases in this section are listed in order:

1) Infinite Normal Array, 0.375" pellet, 4 Boxes, 5.00 wt% UO_2, 100% TD, 0.81 vf, Scrap

2) Infinite Normal Array, 0.375"/0.146" annular pellet, 4 Boxes, 5.00 wt% UO_2, 100% TD, 0.688 vf, Scrap

3) 28x3 Accident Array 0.28"/0.065" Annular Fuel, 4 Boxes, 3.75 wt% UO_2, 100% TD, 0.33 vf, Scrap

4) 28x3 Accident Array 0.315" Solid Fuel, 4 Boxes w/trays, 5.00 wt% UO_2, 98% TD, 0.36 vf, Pellet-Tray

5) Single Flooded Drum 0.200" Solid Fuel, 4 Boxes, 5.00 wt% UO_2, 98% TD, 0.26 vf, Scrap

6) Single Flooded Drum 0.28"/0.065" Solid Fuel, 4 Boxes, 3.75 wt% UO_2, 100% TD, 0.28 vf, Scrap

Infinite Normal Array, 0.375" pellet, 4 Boxes,
5.00 wt% UO_2, 100% TD, 0.81 vf, Scrap

```
=csas2x
27 gp 0.375 0.81vf tri inf norm array dhtf min card
27groupndf4            latticecell
uo2        1   1.000 305 92235 5.0  92238 95.0  end
h2o        2   den=0.000001   end
ss304      3   1.00          end
oak        4   den=0.23227    end
h2o        5   den=0.000001   end
h2o        6   den=0.000001   end
carbonsteel  7   1.00         end
h2o        8   den=0.000001   end
h          9   0.0  7.82813-3  end
c          9   0.0  4.65998-3  end
o          9   0.0  3.88308-3  end
poly(h2o)   10   1.00         end
carbonsteel  11   1.00         end
end comp
triangpitch    1.0071354 0.95250  1  2     end
kenova 0.375 pellet tri pitch 5.0 wt% 0.81 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid   10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid  500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid   10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid    9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ upper fuel block 2 -y !
unit 2
cuboid   10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid  500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid   10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid    9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges -y !
unit 3
cuboid    3 1 2p 0.55499  0.0 -11.58875  2p20.79625
cuboid    0 1 2p 0.55499  0.0 -11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 4
array     1  3*0.0
com=! combine boxes into lower deck array !
unit 5
```

```
array     2  3*0.0
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.82624  -11.826875  -21.43125
replicate   0 1 2*0.397510   0.0 0.396875   2*0.79375  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y   4 1 28.41625  44.926250 -39.211250
zhemicyl-y  11 1 28.52801  45.038010 -39.323010
zhemicyl-y   0 1 28.52801  46.672500 -40.957500
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid    10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid   500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid    10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid   500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +y !
unit 9
cuboid     3 1 2p0.55499  11.58875  0.0 2p20.79625
cuboid     0 1 2p0.55499  11.826875 0.0 2p21.43125
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
unit 11
array     5  3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array      6  -11.82624    0.0     -21.43125
replicate   0 1 2*0.397510   0.396875 0.0   2*0.79375  1
replicate   3 1 2*0.149860   0.149860 0.0   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+y   4 1 28.41625  44.926250 -39.211250
zhemicyl+y  11 1 28.52801  45.038010 -39.323010
zhemicyl+y   0 1 28.52801  46.672500 -40.957500
com=!  lower fuel block 1 +x !
unit 13
cuboid    10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid   500 1 2p5.201285 2p11.532235 2p10.420985
```

```
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  upper fuel block 2 +x !
unit 14
cuboid   10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid  500 1 2p5.201285 2p11.532235 2p10.420985
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid    3 1 0.55499  0.0 2p11.58875  2p20.79625
cuboid    0 1 0.55499  0.0 2p11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 16
array     7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array     8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array      9  0.0       -11.826875 -21.43125
replicate   0 1 0.397510 0.0 2*0.396875   2*0.79375  1
replicate   3 1 0.149860 0.0 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+x   4 1 28.41625  44.926250 -39.211250
zhemicyl+x  11 1 28.52801  45.038010 -39.323010
zhemicyl+x   0 1 28.52801  46.672500 -40.957500
unit 24
array      12  -11.82624   -11.826875 -21.43125
replicate   0 1 0.0 0.397510 2*0.396875   2*0.79375  1
replicate   3 1 0.0 0.149860 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-x   4 1 28.41625  44.926250 -39.211250
zhemicyl-x  11 1 28.52801  45.038010 -39.323010
zhemicyl-x   0 1 28.52801  46.672500 -40.957500
global
unit 25
cuboid    0 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole       6  0.0        28.52802          0.0
hole      12  0.0       -28.52802          0.0
hole      18  -49.411963   0.0             0.0
hole      24   49.411963   0.0             0.0
end geom
read array
ara=1  nux=1   nuy=1  nuz=2
```

```
fill 2  2  end fill
ara=2  nux=1   nuy=1  nuz=2
fill 1  1  end fill
ara=3  nux=3   nuy=1  nuz=1
fill 4  3  5 end fill
ara=4  nux=1   nuy=1  nuz=2
fill 7  7  end fill
ara=5  nux=1   nuy=1  nuz=2
fill 8  8  end fill
ara=6  nux=3   nuy=1  nuz=1
fill 10 9 11 end fill
ara=7  nux=1   nuy=1  nuz=2
fill 13 13  end fill
ara=8  nux=1   nuy=1  nuz=2
fill 14 14  end fill
ara=9  nux=2   nuy=1  nuz=1
fill 15 16    end fill
ara=12  nux=2   nuy=1  nuz=1
fill 17 15 end fill
end array
read plot
pic=mix plt=yes
xul=-50 yul=30   zul=2
xlr=50   ylr=-30 zlr=2
uax=1.0 vdn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=refl -xb=refl +yb=refl -yb=refl +zb=refl -zb=refl
end data
end
```

Infinite Normal Array, 0.375"/0.146" annular pellet, 4 Boxes,
5.00 wt% UO_2, 100% TD, 0.688 vf, Scrap

```
=csas2x
27 gp 0.375 0.688vf tri inf ann norm array dhtf min card
27groupndf4          latticecell
uo2        1   1.000305 92235 5.0  92238 95.0  end
h2o        2   den=0.000001   end
ss304      3   1.00        end
oak        4   den=0.23227   end
h2o        5   den=0.000001   end
h2o        6   den=0.000001   end
carbonsteel  7   1.00        end
h2o        8   den=0.000001   end
h          9   0.0  7.82813-3  end
c          9   0.0  4.65998-3  end
o          9   0.0  3.88308-3  end
poly(h2o)  10   1.00        end
carbonsteel  11   1.00        end
end comp
atriangpitch   1.0071354 0.95250  1  2  0  0.37084  end
kenova 0.375 pellet tri pitch 5.0 wt% 0.81 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid   500 1 2p 5.080000 0.0 -11.074400 2p9.8679000
cuboid     0 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid    10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid     9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ upper fuel block 2 -y !
unit 2
cuboid   500 1 2p 5.080000 0.0 -11.074400 2p9.8679000
cuboid     0 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid    10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid     9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges -y !
unit 3
cuboid     3 1 2p 0.55499  0.0 -11.58875  2p20.79625
cuboid     0 1 2p 0.55499  0.0 -11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 4
array     1  3*0.0
com=! combine boxes into lower deck array !
unit 5
```

```
array     2  3*0.0
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.82624  -11.826875  -21.43125
replicate   0 1 2*0.397510   0.0 0.396875   2*0.79375  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y   4 1 28.41625  44.926250 -39.211250
zhemicyl-y  11 1 28.52801  45.038010 -39.323010
zhemicyl-y   0 1 28.52801  46.672500 -40.957500
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid   500 1 2p5.080000 11.074400 0.0 2p9.8679000
cuboid     0 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid   500 1 2p5.080000 11.074400 0.0 2p9.8679000
cuboid     0 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +y !
unit 9
cuboid     3 1 2p0.55499  11.58875  0.0 2p20.79625
cuboid     0 1 2p0.55499  11.826875 0.0 2p21.43125
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
unit 11
array     5  3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array      6  -11.82624    0.0     -21.43125
replicate   0 1 2*0.397510   0.396875 0.0   2*0.79375  1
replicate   3 1 2*0.149860   0.149860 0.0   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+y   4 1 28.41625  44.926250 -39.211250
zhemicyl+y  11 1 28.52801  45.038010 -39.323010
zhemicyl+y   0 1 28.52801  46.672500 -40.957500
com=!  lower fuel block 1 +x !
unit 13
cuboid   500 1 2p5.080000 2p11.074400 2p9.8679000
cuboid     0 1 2p5.201285 2p11.532235 2p10.420985
```

```
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  upper fuel block 2 +x !
unit 14
cuboid  500 1 2p5.080000 2p11.074400 2p9.8679000
cuboid    0 1 2p5.201285 2p11.532235 2p10.420985
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid    3 1 0.55499  0.0 2p11.58875  2p20.79625
cuboid    0 1 0.55499  0.0 2p11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 16
array     7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array     8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array      9  0.0        -11.826875 -21.43125
replicate   0 1 0.397510 0.0 2*0.396875   2*0.79375  1
replicate   3 1 0.149860 0.0 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+x   4 1 28.41625  44.926250 -39.211250
zhemicyl+x  11 1 28.52801  45.038010 -39.323010
zhemicyl+x   0 1 28.52801  46.672500 -40.957500
unit 24
array      12  -11.82624   -11.826875 -21.43125
replicate   0 1 0.0 0.397510 2*0.396875   2*0.79375  1
replicate   3 1 0.0 0.149860 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-x   4 1 28.41625  44.926250 -39.211250
zhemicyl-x  11 1 28.52801  45.038010 -39.323010
zhemicyl-x   0 1 28.52801  46.672500 -40.957500
global
unit 25
cuboid    0 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole       6  0.0        28.52802        0.0
hole      12  0.0       -28.52802        0.0
hole      18  -49.411963   0.0           0.0
hole      24  49.411963   0.0           0.0
end geom
read array
ara=1  nux=1   nuy=1  nuz=2
```

```
fill 2  2  end fill
ara=2  nux=1   nuy=1  nuz=2
fill 1  1  end fill
ara=3  nux=3   nuy=1  nuz=1
fill 4  3  5 end fill
ara=4  nux=1   nuy=1  nuz=2
fill 7  7  end fill
ara=5  nux=1   nuy=1  nuz=2
fill 8  8  end fill
ara=6  nux=3   nuy=1  nuz=1
fill 10 9 11 end fill
ara=7  nux=1   nuy=1  nuz=2
fill 13 13  end fill
ara=8  nux=1   nuy=1  nuz=2
fill 14 14  end fill
ara=9  nux=2   nuy=1  nuz=1
fill 15 16    end fill
ara=12  nux=2   nuy=1  nuz=1
fill 17 15 end fill
end array
read plot
pic=mix plt=yes
xul=-50 yul=30   zul=2
xlr=50   ylr=-30 zlr=2
uax=1.0 vdn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=refl -xb=refl +yb=refl -yb=refl +zb=refl -zb=refl
end data
end
```

28x3 Accident Array 0.28"/0.065" Annular Fuel, 4 Boxes,
3.75 wt% UO_2, 100% TD, 0.33vf, Scrap

```
=csas2x
27 gp 0.28/0.065 0.33vf tri 28x3 acc array dhtf
27groupndf4          latticecell
uo2        1   1.000 305 92235 3.75 92238 96.25 end
h2o        2   den=1.0      end
ss304      3   1.00       end
oak        4   den=0.23227    end
h2o        5   den=1.0      end
h2o        6   den=1.0      end
carbonsteel  7   1.00       end
h2o        8   den=1.0      end
h          9   0.0  2.37477-2  end
c          9   0.0  1.59965-2  end
o          9   0.0  9.07870-3  end
poly(h2o)  10   1.00       end
carbonsteel  11   1.00       end
al         12   1.00       end
end comp
atriangpitch   1.1467933 0.71120  1  2  8  0.165100   end
kenova 0.280/0.065 pellet tri pitch 3.75 wt% 0.33 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid   10 1 2p 0.165264 0.0 -11.182985 2p10.071735
cuboid  500 1 2p 4.915535 0.0 -11.182985 2p10.071735
cuboid   10 1 2p 4.930775 0.0 -11.198225 2p10.086975
cuboid    9 1 2p 5.159375 0.0 -11.350625 2p10.239375
cuboid  500 1 2p 5.318125 0.0 -11.58875  2p10.398125
com=!  ½ upper fuel block 2 -y !
unit 2
cuboid   10 1 2p 0.165264 0.0 -11.182985 2p10.071735
cuboid  500 1 2p 4.915535 0.0 -11.182985 2p10.071735
cuboid   10 1 2p 4.930775 0.0 -11.198225 2p10.086975
cuboid    9 1 2p 5.159375 0.0 -11.350625 2p10.239375
cuboid  500 1 2p 5.318125 0.0 -11.58875  2p10.398125
com=!  ½ 0.437" ss304 plate on edges -y !
unit 3
cuboid   3 1 2p 0.55499  0.0 -11.58875  2p20.79625
com=! combine boxes into upper deck array !
unit 4
array    1  3*0.0
```

```
com=! combine boxes into lower deck array !
unit 5
array     2  3*0.0
com=!  ½ aluminum spacer block -y !
unit 60
cuboid    12 1 2p 5.318125 0.0 -11.430000 2p10.31875
cuboid   500 1 2p 5.318125 0.0 -11.58875  2p10.398125
com=!  ½ aluminum spacer block +y !
unit 61
cuboid    12 1 2p 5.318125 11.430000 0.0 2p10.31875
cuboid   500 1 2p 5.318125 11.58875  0.0 2p10.398125
com=!  ½ aluminum spacer block +x !
unit 62
cuboid    12 1 2p 5.318125 2p11.430000 2p10.31875
cuboid   500 1 2p 5.318125 2p11.58875  2p10.398125
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.19124  -11.58875   -20.79625
replicate  500 1 2*1.032510   0.0 0.635      2.85750 0.0  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y   4 1 26.74620  46.355000 -37.782500
zhemicyl-y  11 1 26.85796  46.466760 -37.894260
zhemicyl-y   0 1 26.85796  48.101250 -39.528750
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid    10 1 2p 0.165264 11.182985 0.0 2p10.071735
cuboid   500 1 2p 4.915535 11.182985 0.0 2p10.071735
cuboid    10 1 2p 4.930775 11.198225 0.0 2p10.086975
cuboid     9 1 2p 5.159375 11.350625 0.0 2p10.239375
cuboid   500 1 2p 5.318125 11.58875  0.0 2p10.398125
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid    10 1 2p 0.165264 11.182985 0.0 2p10.071735
cuboid   500 1 2p 4.915535 11.182985 0.0 2p10.071735
cuboid    10 1 2p 4.930775 11.198225 0.0 2p10.086975
cuboid     9 1 2p 5.159375 11.350625 0.0 2p10.239375
cuboid   500 1 2p 5.318125 11.58875  0.0 2p10.398125
com=!  ½ 0.437" ss304 plate on edges +y !
unit 9
cuboid     3 1 2p 0.55499  11.58875  0.0 2p20.79625
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
```

```
unit 11
array     5  3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array      6  -11.19124   0.0    -20.79625
replicate  500 1 2*1.032510   0.635     0.0   2.85750 0.0      1
replicate   3 1 2*0.149860   0.149860  0.0   0.0     0.47625  1
replicate   11 1 4*0.0        0.79375  0.0   1
zhemicyl+y   4 1 26.74620  46.355000 -37.782500
zhemicyl+y  11 1 26.85796  46.466760 -37.894260
zhemicyl+y   0 1 26.85796  48.101250 -39.528750
com=!  lower fuel block 1 +x !
unit 13
cuboid    10 1 2p 0.165264  2p11.182985 2p10.071735
cuboid   500 1 2p 4.915535  2p11.182985 2p10.071735
cuboid    10 1 2p 4.930775  2p11.198225 2p10.086975
cuboid     9 1 2p 5.159375  2p11.350625 2p10.239375
cuboid   500 1 2p 5.318125  2p11.58875  2p10.398125
com=!  upper fuel block 2 +x !
unit 14
cuboid    10 1 2p 0.165264  2p11.182985 2p10.071735
cuboid   500 1 2p 4.915535  2p11.182985 2p10.071735
cuboid    10 1 2p 4.930775  2p11.198225 2p10.086975
cuboid     9 1 2p 5.159375  2p11.350625 2p10.239375
cuboid   500 1 2p 5.318125  2p11.58875  2p10.398125
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid     3 1 0.55499  0.0 2p11.58875  2p20.79625
com=! combine boxes into upper deck array !
unit 16
array     7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array     8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array      9  0.0        -11.5887501   -20.7962501
replicate  500 1 1.032510 0.0   2*0.635     2.85750 0.0      1
replicate   3 1 0.149860 0.0   2*0.149860  0.0     0.47625  1
replicate   11 1 4*0.0        0.79375  0.0   1
zhemicyl+x   4 1 26.74620  46.355000 -37.782500
zhemicyl+x  11 1 26.85796  46.466760 -37.894260
zhemicyl+x   0 1 26.85796  48.101250 -39.528750
unit 24
array      12  -11.191240  -11.5887501   -20.7962501
```

```
replicate 500 1 0.0 1.032510  2*0.635    2.85750 0.0    1
replicate  3 1 0.0 0.149860  2*0.149860  0.0    0.47625  1
replicate  11 1 4*0.0       0.79375  0.0   1
zhemicyl-x  4 1 26.74620  46.355000 -37.782500
zhemicyl-x  11 1 26.85796  46.466760 -37.894260
zhemicyl-x  0 1 26.85796  48.101250 -39.528750
unit 25
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole    12  0.0      -26.857962       0.0
hole    18 -46.519354   0.0           0.0
hole    24  46.519354   0.0           0.0
unit 26
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole    12  0.0      -26.857962       0.0
hole    18 -46.519354   0.0           0.0
unit 27
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole    12  0.0      -26.857962       0.0
hole    18 -46.519354   0.0           0.0
unit 28
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
unit 29
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole    18 -46.519354   0.0           0.0
unit 30
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole    24  46.519354   0.0           0.0
unit 31
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole    12  0.0      -26.857962       0.0
hole    24  46.519354   0.0           0.0
unit 32
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole    18 -46.519354   0.0           0.0
unit 33
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole    24  46.519354   0.0           0.0
unit 34
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole    12  0.0      -26.857962       0.0
unit 35
```

```
cuboid    0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole      6  0.0       26.857962       0.0
unit 36
cuboid    0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole      6  0.0       26.857962       0.0
hole     12  0.0       -26.857962      0.0
hole     24  46.519354  0.0            0.0
unit 37
array 13   0.0       -161.1478    -39.528760
cuboid     0 1 190.00  0.0  162.00 -162.00   48.101251 -39.52877
global
unit 38
array 14   0.0  -162.00     -127.1588
replicate  5  2  3.0 0.0 4*3.0   11
end geom
read array
ara=1  nux=1   nuy=1  nuz=2
fill 2  2  end fill
ara=2  nux=1   nuy=1  nuz=2
fill 1  1  end fill
ara=3  nux=3   nuy=1  nuz=1
fill 4  3  5 end fill
ara=4  nux=1   nuy=1  nuz=2
fill 7  7  end fill
ara=5  nux=1   nuy=1  nuz=2
fill 8  8  end fill
ara=6  nux=3   nuy=1  nuz=1
fill 10 9 11 end fill
ara=7  nux=1   nuy=1  nuz=2
fill 13 13  end fill
ara=8  nux=1   nuy=1  nuz=2
fill 14 14  end fill
ara=9  nux=2   nuy=1  nuz=1
fill 15 16 end fill
ara=12  nux=2   nuy=1  nuz=1
fill 17 15 end fill
ara=13  nux=2   nuy=6 nuz=1
fill 35 28 25 29 25 26 25 26 25 27 34 28  end fill
ara=14  nux=1   nuy=1  nuz=3
fill f37 end fill
end array
read bias id=500 2 12  end bias
read plot
pic=mix plt=yes
xul=280 yul=-280  zul=10
```

```
xlr=0    ylr=280  zlr=10
uax=1.0 vdn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=vac  -xb=refl +yb=vac  -yb=vac  +zb=vac  -zb=vac
end data
end
```

28x3 Accident Array 0.315" Solid Fuel, 4 Boxes w/trays,
5.00 wt% UO_2, 98% TD, 0.36 vf, Pellet-Tray

```
=csas2x
27 gp 0.315 0.36vf tri pellet-tray 28x3 acc dhtf
27groupndf4          latticecell
uo2        1   0.980 305 92235 5.0  92238 95.0  end
h2o        2   den=1.0       end
ss304      3   1.00          end
oak        4   den=0.23227    end
h2o        5   den=1.0       end
h2o        6   den=1.0       end
carbonsteel  7   1.00         end
h2o        8   den=1.0       end
h          9   0.0  2.37477-2  end
c          9   0.0  1.59965-2  end
o          9   0.0  9.07870-3  end
poly(h2o)   10   1.00         end
carbonsteel  11   1.00         end
al         12   1.00          end
end comp
triangpitch    1.269909 0.80010  1   2  end
kenova 0.315 solid pellet tri pitch 5.0 wt% 0.36 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid      3 1 2p 0.020955 0.0 -11.023600 2p9.8171000
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.0      0.0   0.159385  2*0.254635 1
replicate   10 1 2*0.1652640 4*0.0 1
replicate   10 1 2*0.01524   0.0 0.01524  2*0.01524  1
replicate    9 1 2*0.2286    0.0 0.1524   2*0.1524  1
replicate  500 1 2*0.15875   0.0 0.238125 2*0.15875  1
com=!  ½ upper fuel block 2 -y !
unit 2
```

```
cuboid     3 1 2p 0.020955 0.0 -11.023600 2p9.8171000
replicate 500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.0      0.0  0.159385  2*0.254635 1
replicate  10 1 2*0.1652640 4*0.0 1
replicate  10 1 2*0.01524   0.0 0.01524  2*0.01524  1
replicate   9 1 2*0.2286    0.0 0.1524   2*0.1524  1
replicate 500 1 2*0.15875   0.0 0.238125 2*0.15875  1
com=!  ½ 0.437" ss304 plate on edges -y !
unit 3
cuboid    3 1 2p 0.55499  0.0 -11.58875  2p20.79625
com=! combine boxes into upper deck array !
unit 4
array     1  3*0.0
com=! combine boxes into lower deck array !
unit 5
array     2  3*0.0
com=!  ½ aluminum spacer block -y !
unit 60
cuboid   12 1 2p 5.318125 0.0 -11.430000 2p10.31875
cuboid  500 1 2p 5.318125 0.0 -11.58875  2p10.398125
com=!  ½ aluminum spacer block +y !
unit 61
cuboid   12 1 2p 5.318125 11.430000 0.0 2p10.31875
cuboid  500 1 2p 5.318125 11.58875  0.0 2p10.398125
com=!  ½ aluminum spacer block +x !
unit 62
cuboid   12 1 2p 5.318125 2p11.430000 2p10.31875
cuboid  500 1 2p 5.318125 2p11.58875  2p10.398125
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.19124  -11.58875   -20.79625
replicate 500 1 2*1.032510   0.0 0.635      2.85750 0.0  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y  4 1 26.74620  46.355000 -37.782500
zhemicyl-y 11 1 26.85796  46.466760 -37.894260
```

```
zhemicyl-y  0 1 26.85796  48.101250 -39.528750
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid     3 1 2p 0.020955 11.023600 0.0 2p9.8171000
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.0      0.159385 0.0  2*0.254635 1
replicate   10 1 2*0.1652640 4*0.0 1
replicate   10 1 2*0.01524   0.01524  0.0  2*0.01524 1
replicate    9 1 2*0.2286    0.1524   0.0  2*0.1524 1
replicate  500 1 2*0.15875   0.238125 0.0  2*0.15875 1
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid     3 1 2p 0.020955 11.023600 0.0 2p9.8171000
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.9039532 4*0.0 1
replicate   3 1 2*0.0419100 4*0.0 1
replicate  500 1 2*0.0      0.159385 0.0  2*0.254635 1
replicate   10 1 2*0.1652640 4*0.0 1
replicate   10 1 2*0.01524   0.01524  0.0  2*0.01524 1
replicate    9 1 2*0.2286    0.1524   0.0  2*0.1524 1
replicate  500 1 2*0.15875   0.238125 0.0  2*0.15875 1
com=!  ½ 0.437" ss304 plate on edges +y !
unit 9
cuboid    3 1 2p 0.55499  11.58875  0.0 2p20.79625
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
unit 11
```

```
array     5 3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array     6 -11.19124  0.0    -20.79625
replicate 500 1 2*1.032510  0.635    0.0  2.85750 0.0    1
replicate  3 1 2*0.149860  0.149860 0.0  0.0    0.47625 1
replicate 11 1 4*0.0       0.79375 0.0  1
zhemicyl+y  4 1 26.74620  46.355000 -37.782500
zhemicyl+y 11 1 26.85796  46.466760 -37.894260
zhemicyl+y  0 1 26.85796  48.101250 -39.528750
com=!  lower fuel block 1 +x !
unit 13
cuboid     3 1 2p 0.020955 2p 11.023600  2p9.8171000
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.0      2*0.159385   2*0.254635 1
replicate 10 1 2*0.1652640 4*0.0 1
replicate 10 1 2*0.01524  2*0.01524    2*0.01524 1
replicate  9 1 2*0.2286   2*0.1524     2*0.1524 1
replicate 500 1 2*0.15875  2*0.238125   2*0.15875 1
com=!  upper fuel block 2 +x !
unit 14
cuboid     3 1 2p 0.020955 2p 11.023600  2p9.8171000
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.9039532 4*0.0 1
replicate  3 1 2*0.0419100 4*0.0 1
replicate 500 1 2*0.0      2*0.159385   2*0.254635 1
replicate 10 1 2*0.1652640 4*0.0 1
replicate 10 1 2*0.01524  2*0.01524    2*0.01524 1
replicate  9 1 2*0.2286   2*0.1524     2*0.1524 1
```

```
replicate  500 1 2*0.15875   2*0.238125    2*0.15875 1
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid     3 1 0.55499  0.0 2p11.58875  2p20.79625
com=! combine boxes into upper deck array !
unit 16
array      7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array      8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array       9   0.0        -11.5887501   -20.7962501
replicate  500 1 1.032510 0.0   2*0.635     2.85750 0.0      1
replicate   3 1 0.149860 0.0   2*0.149860  0.0     0.47625  1
replicate   11 1 4*0.0        0.79375  0.0    1
zhemicyl+x   4 1 26.74620  46.355000 -37.782500
zhemicyl+x  11 1 26.85796  46.466760 -37.894260
zhemicyl+x   0 1 26.85796  48.101250 -39.528750
unit 24
array      12   -11.191250  -11.5887501   -20.7962501
replicate  500 1 0.0 1.032510   2*0.635     2.85750 0.0      1
replicate   3 1 0.0 0.149860   2*0.149860  0.0     0.47625  1
replicate   11 1 4*0.0        0.79375  0.0    1
zhemicyl-x   4 1 26.74620  46.355000 -37.782500
zhemicyl-x  11 1 26.85796  46.466760 -37.894260
zhemicyl-x   0 1 26.85796  48.101250 -39.528750
unit 25
cuboid     0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole       6   0.0        26.857962        0.0
hole      12   0.0        -26.857962        0.0
hole      18  -46.519354   0.0             0.0
hole      24   46.519354   0.0             0.0
unit 26
cuboid     0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole       6   0.0        26.857962        0.0
hole      12   0.0        -26.857962        0.0
hole      18  -46.519354   0.0             0.0
unit 27
cuboid     0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole      12   0.0        -26.857962        0.0
hole      18  -46.519354   0.0             0.0
unit 28
cuboid     0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
unit 29
```

```
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole     18 -46.519354  0.0           0.0
unit 30
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole     24  46.519354  0.0           0.0
unit 31
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     12  0.0      -26.857962       0.0
hole     24  46.519354  0.0           0.0
unit 32
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     18 -46.519354  0.0           0.0
unit 33
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     24  46.519354  0.0           0.0
unit 34
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     12  0.0      -26.857962       0.0
unit 35
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
unit 36
cuboid   0 1 46.519354 -46.519354 26.857962 -26.857962 48.101250 -39.528750
hole     6  0.0       26.857962       0.0
hole     12  0.0      -26.857962       0.0
hole     24  46.519354  0.0           0.0
unit 37
array 13  0.0      -161.1478    -39.528760
cuboid    0 1 190.00  0.0  162.00 -162.00   48.101251 -39.52877
global
unit 38
array 14  0.0  -162.00     -127.1588
replicate 5  2  3.0 0.0 4*3.0  11
end geom
read array
ara=1  nux=1  nuy=1  nuz=2
fill 2  2  end fill
ara=2  nux=1  nuy=1  nuz=2
fill 1  1  end fill
ara=3  nux=3  nuy=1  nuz=1
fill 4  3  5 end fill
ara=4  nux=1  nuy=1  nuz=2
fill 7  7  end fill
```

```
ara=5  nux=1   nuy=1  nuz=2
fill 8  8  end fill
ara=6  nux=3   nuy=1  nuz=1
fill 10 9 11 end fill
ara=7  nux=1   nuy=1  nuz=2
fill 13 13  end fill  .
ara=8  nux=1   nuy=1  nuz=2
fill 14 14  end fill
ara=9  nux=2   nuy=1  nuz=1
fill 15 16 end fill
ara=12  nux=2   nuy=1  nuz=1
fill 17 15 end fill
ara=13  nux=2   nuy=6 nuz=1
fill 35 28 25 29 25 26 25 26 25 27 34 28  end fill
ara=14  nux=1   nuy=1  nuz=3
fill f37 end fill
end array
read bias id=500 2 12  end bias
read plot
pic=mix plt=yes
xul=280 yul=-280  zul=10
xlr=0    ylr=280  zlr=10
uax=1.0 vdn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=vac  -xb=refl +yb=vac  -yb=vac  +zb=vac  -zb=vac
end data
end
```

Single Flooded Drum 0.200" Solid Fuel, 4 Boxes,
5.00 wt% UO_2, 98% TD, 0.26 vf, Scrap

```
=csas2x
27 gp 0.200 0.26vf tri inf norm array dhtf min card
27groupndf4            latticecell
uo2        1   0.980 305 92235 5.00 92238 95.00  end
h2o        2   den=1.0       end
ss304      3   1.00          end
oak        4   den=0.23227    end
h2o        5   den=1.0       end
h2o        6   den=1.0       end
carbonsteel  7   1.00         end
h2o        8   den=1.0       end
h          9   0.0  7.82813-3  end
c          9   0.0  4.65998-3  end
o          9   0.0  3.88308-3  end
poly(h2o)   10   1.00         end
carbonsteel  11   1.00         end
end comp
triangpitch    0.94876   0.50800  1  2     end
kenova 0.200 pellet tri pitch 5.00wt% 0.26 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid    10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid   500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid    10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid     9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ upper fuel block 2 -y !
unit 2
cuboid    10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid   500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid    10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid     9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges -y !
unit 3
cuboid     3 1 2p 0.55499  0.0 -11.58875  2p20.79625
cuboid     5 1 2p 0.55499  0.0 -11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 4
array     1  3*0.0
com=! combine boxes into lower deck array !
unit 5
```

```
array     2  3*0.0
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.82624  -11.826875  -21.43125
replicate   5 1 2*0.397510   0.0 0.396875   2*0.79375  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y   4 1 28.41625  44.926250 -39.211250
zhemicyl-y  11 1 28.52801  45.038010 -39.323010
zhemicyl-y   5 1 28.52801  46.672500 -40.957500
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid    10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid   500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid    10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid   500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid    10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid     9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +y !
unit 9
cuboid     3 1 2p0.55499  11.58875  0.0 2p20.79625
cuboid     5 1 2p0.55499  11.826875 0.0 2p21.43125
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
unit 11
array     5  3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array      6  -11.82624    0.0     -21.43125
replicate   5 1 2*0.397510   0.396875 0.0   2*0.79375  1
replicate   3 1 2*0.149860   0.149860 0.0   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+y   4 1 28.41625  44.926250 -39.211250
zhemicyl+y  11 1 28.52801  45.038010 -39.323010
zhemicyl+y   5 1 28.52801  46.672500 -40.957500
com=!  lower fuel block 1 +x !
unit 13
cuboid    10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid   500 1 2p5.201285 2p11.532235 2p10.420985
```

```
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  upper fuel block 2 +x !
unit 14
cuboid   10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid  500 1 2p5.201285 2p11.532235 2p10.420985
cuboid   10 1 2p5.216525 2p11.547475 2p10.436225
cuboid    9 1 2p5.635625 2p11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid    3 1 0.55499  0.0 2p11.58875  2p20.79625
cuboid    5 1 0.55499  0.0 2p11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 16
array     7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array     8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array     9  0.0       -11.826875 -21.43125
replicate   5 1 0.397510 0.0 2*0.396875   2*0.79375  1
replicate   3 1 0.149860 0.0 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+x   4 1 28.41625  44.926250 -39.211250
zhemicyl+x  11 1 28.52801  45.038010 -39.323010
zhemicyl+x   5 1 28.52801  46.672500 -40.957500
unit 24
array     12   -11.82624   -11.826875 -21.43125
replicate   5 1 0.0 0.397510 2*0.396875   2*0.79375  1
replicate   3 1 0.0 0.149860 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-x   4 1 28.41625  44.926250 -39.211250
zhemicyl-x  11 1 28.52801  45.038010 -39.323010
zhemicyl-x   5 1 28.52801  46.672500 -40.957500
unit 25
cuboid    5 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole      6  0.0        28.52802          0.0
unit 26
cuboid    5 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole     12  0.0       -28.52802          0.0
global
unit 28
array 13  -49.411964    -57.0561    -40.957610
cuboid    5 1 49.41197 -49.41197 57.0561  -57.0561  46.67261 -40.95762
```

```
replicate  5 2 6*3.0  22
end geom
read array
ara=1 nux=1  nuy=1 nuz=2
fill 2 2 end fill
ara=2 nux=1  nuy=1 nuz=2
fill 1 1 end fill
ara=3 nux=3  nuy=1 nuz=1
fill 4 3 5 end fill
ara=4 nux=1  nuy=1 nuz=2
fill 7 7 end fill
ara=5 nux=1  nuy=1 nuz=2
fill 8 8 end fill
ara=6 nux=3  nuy=1 nuz=1
fill 10 9 11 end fill
ara=7 nux=1  nuy=1 nuz=2
fill 13 13 end fill
ara=8 nux=1  nuy=1 nuz=2
fill 14 14 end fill
ara=9 nux=2  nuy=1 nuz=1
fill 15 16   end fill
ara=12 nux=2  nuy=1 nuz=1
fill 17 15 end fill
ara=13 nux=1  nuy=2 nuz=1
fill 25 26 end fill
end array
read bias id=500 2 23   end bias
read plot
pic=mix plt=yes
xul=50   yul=-50   zul=10
xlr=-50  ylr=50   zlr=10
vax=1.0 udn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=vac -xb=vac +yb=vac -yb=vac +zb=vac -zb=vac
end data
end
```

Single Flooded Drum 0.28"/0.065" Solid Fuel, 4 Boxes,
3.75 wt% UO_2, 100% TD, 0.28 vf,Scrap

```
=csas2x
27 gp 0.28/0.065 0.28vf tri inf norm array dhtf min card
27groupndf4            latticecell
uo2          1   1.000 305 92235 3.75 92238 96.25  end
h2o          2   den=1.0        end
ss304        3   1.00           end
oak          4   den=0.23227    end
h2o          5   den=1.0        end
h2o          6   den=1.0        end
carbonsteel  7   1.00           end
h2o          8   den=1.0        end
h            9   0.0  7.82813-3  end
c            9   0.0  4.65998-3  end
o            9   0.0  3.88308-3  end
poly(h2o)   10   1.00           end
carbonsteel 11   1.00           end
end comp
atriangpitch    1.2449821 0.71120  1  2  8  0.1651   end
kenova 0.28/0.065 pellet tri pitch 3.75wt% 0.28 vf dhtf
read parm tme=4800 tba=3 gen=850 npg=1500 run=yes plt=yes end parm
read geom
com=!  ½ lower fuel block 1 -y !
unit 1
cuboid   10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid  500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid   10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid    9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ upper fuel block 2 -y !
unit 2
cuboid   10 1 2p 0.170333 0.0 -11.074400 2p9.8679000
cuboid  500 1 2p 5.201285 0.0 -11.532235 2p10.420985
cuboid   10 1 2p 5.216525 0.0 -11.547475 2p10.436225
cuboid    9 1 2p 5.635625 0.0 -11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges -y !
unit 3
cuboid    3 1 2p 0.55499  0.0 -11.58875  2p20.79625
cuboid    5 1 2p 0.55499  0.0 -11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 4
array     1  3*0.0
com=! combine boxes into lower deck array !
unit 5
```

```
array     2  3*0.0
com=! combine upper and lower decks with ss304 plate -y !
unit 6
array      3 -11.82624  -11.826875  -21.43125
replicate   5 1 2*0.397510   0.0 0.396875   2*0.79375  1
replicate   3 1 2*0.149860   0.0 0.149860   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-y  4 1 28.41625  44.926250 -39.211250
zhemicyl-y  11 1 28.52801  45.038010 -39.323010
zhemicyl-y  5 1 28.52801  46.672500 -40.957500
com=!  ½ lower fuel block 1 +y !
unit 7
cuboid   10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid  500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid   10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid    9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ upper fuel block 2 +y !
unit 8
cuboid   10 1 2p0.170333 11.074400 0.0 2p9.8679000
cuboid  500 1 2p5.201285 11.532235 0.0 2p10.420985
cuboid   10 1 2p5.216525 11.547475 0.0 2p10.436225
cuboid    9 1 2p5.635625 11.826875 0.0 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +y !
unit 9
cuboid    3 1 2p0.55499  11.58875  0.0 2p20.79625
cuboid    5 1 2p0.55499  11.826875 0.0 2p21.43125
com=! combine boxes into upper deck array !
unit 10
array     4  3*0.0
com=! combine boxes into lower deck array !
unit 11
array     5  3*0.0
com=! combine upper and lower decks with ss304 plate +y !
unit 12
array      6  -11.82624    0.0     -21.43125
replicate   5 1 2*0.397510   0.396875 0.0   2*0.79375  1
replicate   3 1 2*0.149860   0.149860 0.0   0.0  0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+y  4 1 28.41625  44.926250 -39.211250
zhemicyl+y  11 1 28.52801  45.038010 -39.323010
zhemicyl+y  5 1 28.52801  46.672500 -40.957500
com=!  lower fuel block 1 +x !
unit 13
cuboid   10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid  500 1 2p5.201285 2p11.532235 2p10.420985
```

```
cuboid    10 1 2p5.216525 2p11.547475 2p10.436225
cuboid     9 1 2p5.635625 2p11.826875 2p10.715625
com=!  upper fuel block 2 +x !
unit 14
cuboid    10 1 2p0.170333 2p11.074400 2p9.8679000
cuboid   500 1 2p5.201285 2p11.532235 2p10.420985
cuboid    10 1 2p5.216525 2p11.547475 2p10.436225
cuboid     9 1 2p5.635625 2p11.826875 2p10.715625
com=!  ½ 0.437" ss304 plate+h20 on edges +x !
unit 15
cuboid     3 1 0.55499  0.0 2p11.58875  2p20.79625
cuboid     5 1 0.55499  0.0 2p11.826875 2p21.43125
com=! combine boxes into upper deck array !
unit 16
array      7  3*0.0
com=! combine boxes into lower deck array !
unit 17
array      8  3*0.0
com=! combine upper and lower decks with ss304 plate +x !
unit 18
array      9  0.0        -11.826875 -21.43125
replicate   5 1 0.397510 0.0 2*0.396875   2*0.79375  1
replicate   3 1 0.149860 0.0 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl+x  4 1 28.41625  44.926250 -39.211250
zhemicyl+x  11 1 28.52801  45.038010 -39.323010
zhemicyl+x   5 1 28.52801  46.672500 -40.957500
unit 24
array      12   -11.82624   -11.826875 -21.43125
replicate   5 1 0.0 0.397510 2*0.396875   2*0.79375  1
replicate   3 1 0.0 0.149860 2*0.149860   0.0      0.47625  1
replicate  11 1 4*0.0        0.79375  0.0    1
zhemicyl-x   4 1 28.41625  44.926250 -39.211250
zhemicyl-x  11 1 28.52801  45.038010 -39.323010
zhemicyl-x   5 1 28.52801  46.672500 -40.957500
unit 25
cuboid     5 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole       6  0.0        28.52802          0.0
unit 26
cuboid     5 1 49.411963 -49.411963 28.52802  -28.52802  46.672600 -40.957600
hole      12  0.0       -28.52802          0.0
global
unit 28
array 13  -49.411964    -57.0561    -40.957610
cuboid     5 1 49.41197 -49.41197 57.0561  -57.0561  46.67261 -40.95762
```

```
replicate  5 2 6*3.0  22
end geom
read array
ara=1 nux=1  nuy=1 nuz=2
fill 2 2 end fill
ara=2 nux=1  nuy=1 nuz=2
fill 1 1 end fill
ara=3 nux=3  nuy=1 nuz=1
fill 4 3 5 end fill
ara=4 nux=1  nuy=1 nuz=2
fill 7 7 end fill
ara=5 nux=1  nuy=1 nuz=2
fill 8 8 end fill
ara=6 nux=3  nuy=1 nuz=1
fill 10 9 11 end fill
ara=7 nux=1  nuy=1 nuz=2
fill 13 13 end fill
ara=8 nux=1  nuy=1 nuz=2
fill 14 14 end fill
ara=9 nux=2  nuy=1 nuz=1
fill 15 16  end fill
ara=12 nux=2  nuy=1 nuz=1
fill 17 15 end fill
ara=13 nux=1  nuy=2 nuz=1
fill 25 26 end fill
end array
read bias id=500 2 23  end bias
read plot
pic=mix plt=yes
xul=50  yul=-50  zul=10
xlr=-50  ylr=50  zlr=10
vax=1.0 udn=-1.0 nch='.@' nax=100 end
end plot
read bnds +xb=vac -xb=vac +yb=vac -yb=vac +zb=vac -zb=vac
end data
end
```

6.7 References

1) Title 10 Code of Federal Regulations Part 71 (10CFR71)

2) "SCALE 4.2 - Modular Code System for Performing Standardized Computer Analyses For Licensing Evaluation," ORNL CCC-545, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1993.

3) BWFC Document No. 38-1210382-00, "Nuc. Crit. Safety Eval. - UNC2901 Ship Cont.," 09/15/93.

7.1 General

All operating procedures used for the DHTF shipping container are in compliance with Subpart D of 10 CFR 71 as described below. All operating procedures for the DHTF are approved by FANP Plant Management. All appropriate areas of packaging, shipping, labeling, loading and unloading are covered in the operating procedures as described below. FANP will utilize the DHTF container in compliance with 10 CFR 20.1906, "Procedures for Picking Up, Receiving, and Opening Packages".

7.2 Procedures for Loading the DHTF

7.2.1 If shipping pellets on corrugated stainless steel trays, pellet boxes shall be loaded such that the following requirements are met:

- Maximum enrichment of 5.0% U-235
- Maximum net weight of 112 kgs or 28.0 kgs/box
- Labeled as to serial number, contents, net weight and enrichment
- Maximum of 149 grms of plastic
- Ensure that the stainless steel plate is present
- 4 boxes of pellets
- Pellet dimensions within defined range

7.2.2 If shipping bagged UO_2 (solid pellets, scrap or annular pellets) $\leq$ 5.00%, pellet boxes shall be loaded such that the following requirements are met:

- Maximum enrichment of 5.0% U-235
- Maximum net weight of 84 kgs or 28.0 kgs/box
- Labeled as to serial number, contents, net weight and enrichment
- Maximum of 149 grms of plastic
- Ensure that the stainless steel plate is present
- 3 boxes of pellets with Aluminum spacer filling void space
- Pellet dimensions within defined range

7.2.3 If shipping bagged UO_2 (solid pellets or scrap) $\leq$ 3.85%, pellet boxes shall be loaded such that the following requirements are met:

- Maximum enrichment of 3.85% U-235
- Maximum net weight of 112 kgs or 28.0 kgs/box
- Labeled as to serial number, contents, net weight and enrichment
- Maximum of 149 grms of plastic
- Ensure that the stainless steel plate is present
- 4 boxes of pellets
- Pellet dimensions within defined range

7.2.4 If shipping bagged UO_2 (solid pellets, scrap or annular pellets) $\leq 3.75\%$, pellet boxes shall be loaded such that the following requirements are met:

- Maximum enrichment of 3.75% U-235
- Maximum net weight of 112 kgs or 28.0 kgs/box
- Labeled as to serial number, contents, net weight and enrichment
- Maximum of 149 grms of plastic
- Ensure that the stainless steel plate is present
- 4 boxes of pellets
- Pellet dimensions within defined range

7.2.5 Each DHTF shipping container shall be inspected prior to each use to assure that the following requirements are met:

- No holes (excluding vent holes) in the out drum, no dents greater then one-half inch deep
- Lid gasket not broken or deteriorated
- Inner container gasket replaced at any signs of visual degradation
- Inner container is closed with eight bolts
- Unbroken tamper seal is in place and the outer drum is securely closed
- Outer drum has at least two yellow radioactive labels that indicate contents, fissile class, number of curies and transport index

7.2.6 Each outer drum shall be inspected to assure it is marked as follows:

- Radioactive material
- Package ID Number (USA/9203/AF, Type A)
- Model number (DHTF)
- Serial number
- Gross weight (not to exceed 490 lbs.)
- Owner's name and address

7.2.7 Each DHTF package shall be surveyed prior to each use to assure:

- Removable surface contamination ≤ 2200 dpm per 100 cm^2
- Radiation levels ≤ 200 mrem per hour on contact
- Radiation levels ≤ 10 mrem per hour at 1 meter

7.2.8 Each shipment involving the DHTF package shall have the following records retained for a minimum of three years:

- SNM content of each DHTF package, and of each pellet box within each DHTF
- Form NRC-741 for the shipment
- Package inspection records showing conformance to 7.2.5-7.2.6 above
- Contamination and radiation survey results
- Serial numbers of tamper seals applied to each DHTF
- And other requirements of 10 CRF 71.91

7.2.9 Internal procedures shall be written and maintained to assure that the above steps are incorporated into the work habits of workforce personnel.

7.3 Procedures for Unloading the DHTF

7.3.1 Prior to unloading, each shipment shall be checked to assure that it is accompanied by the following information:

- Form NRC-741
- SNM content of each DHTF package, and of each pellet box within each DHTF
- Serial numbers of tamper seals applied to each DHTF

7.3.2 At least a sampling of the DHTF packages shall be surveyed prior to unloading to assure:

- Removable surface contamination $\leq$ 2200 dpm per 100 cm^2
- Radiation levels $\leq$ 200 mrem per hour on contact
- Radiation levels $\leq$ 10 mrem per hour at 1 meter

7.3.3 Prior to opening any packages, tamper seals shall be checked to assure they are unbroken. Serial numbers must agree with shipper's records.

7.3.4 The outer drums and inner containers may then be opened, and pellet boxes unloaded. Individual pellet boxes shall be weighted and/or sampled as necessary to establish a valid Receiver's SNM value for the shipment.

7.4 Preparation of an Empty DHTF for Transport

7.4.1 Each DHTF shipping container shall be inspected prior to shipment to assure that the following requirements are met:

- Inner container is empty
- Inner container gasket is attached, and had no holes or tears
- Inner container lid is secured in place
- Outer drum lid is bolted in place
- An "Empty" label is affixed

7.4.2 Each outer drum shall be surveyed to assure removable surface contamination $\leq$ 2200 dpm per 100 cm^2

7.5 Shipment Records

Records pertaining to DHTF shipments are retained for a minimum of three years as required by 10 CFR 71.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 General

All procedures for DHTF acceptance tests and maintenance are approved by DNFP Plant Management. These procedures identify the routine inspection and maintenance requirements and acceptance criteria to be applied.

8.2 Acceptance Tests

The DHTF shipping package will be constructed or refurbished in accordance with the licensed drawings in Appendix 1.3. Changes to the design of the package which fall outside the specifications in the license drawings will be submitted to the NRC for approval.

8.2.1 Visual Inspection shall be made of each DHTF package prior to initial use to assure the following requirements are met:

- No holes in the outer drum, nor dents greater than one-half inch deep
- Lid gaskets not broken or deteriorated
- Lid lip and top drum curl are not damaged to the extent that the closure ring will not fit the outer drum
- Outer drum has four vent holes near the top (3/8-inch diameter) covered with tape to preclude entry of water
- Inner container is closed with eight 3/8-inch bolts
- Fiberboard is loaded to the top of the outer drum
- Stainless steel plate provided

8.2.2 Components

- Drums shall be certified by the supplier as DOT 17C or UN1A2/X400/S
- Fiberboard shall be checked to assure the density range of 16.5 lbs. ± 2 lbs.
- The inner container and stainless steel plate shall be measured to assure dimension in accordance with the license drawing, and welds shall be inspected as required by the license drawing
- Inner container gaskets shall be silicon rubber

8.3 Maintenance Program

The DHTF package is not a pressure vessel, employs no shielding materials, and does not require a cooling system or other thermal mechanism for dissipation of heat. Materials of construction are commonplace, durable and readily available. The package contains no systems or subsystems such as valve, rupture disks, or other moving components. As such, the maintenance program for the DHTF consists of repair, refurbishment, or replacement as necessary. Packages are visually inspected prior to each use, and deficiencies noted and recorded at that time. Prior to each shipment, the insert (containment vessel) gasket shall be visually inspected and replaced if defective or with signs of visual degradation.

Packages with unacceptable conditions are sidelined until the package or component can be redressed. For example, a shipping container with a torn inner gasket will not be used until a replacement gasket is procured; a DHTF who outer drum with a hole or large dent will be removed from service until a replacement DOT 17C or Un1Ad/X400/S drum is obtained; etc.

Inspection prior to each use, and refurbishment prior to next use whenever deficiencies are noted, comprise the maintenance program for the DHTF shipping container.

The FANP will utilize a tare weight verification program to check for moisture content buildup in the fiberboard. Each DHTF container will have a unique tare weight associated with it. At least annually, the tare weights of the DHTF container will be checked to verify that there has not been a significant weight gain due to moisture content. Any container showing a significant weight gain (+ 10 pounds) will be visually inspected and all or part of the fiberboard packing material will be replaced if shown to be degraded by excess moisture. If the fiberboard is found to be acceptable, a new tare weight will be established for the DHTF container.

9. CONFORMANCE TO INTERNATIONAL STANDARDS

9.1 Introduction

Since the DHTF Package will be used for international shipments of radioactive materials, it has been designed and tested to demonstrate conformance both to NRC regulations and IAEA standards. This chapter of this license application demonstrates compliance with IAEA's "Regulations for the Safe Transport of Radioactive Materials -- 1973 Revised Edition (As Amended)" and to the 1985 Edition.

9.2 Conformance

The DHTF package complies with IAEA standards for both Type A and Type B(U) Packages, as demonstrated in Tables 9.1 and 9.3. These tables list requirements contained in:

- Section II (1973), Packaging and Package Design Requirements
- Section VI (1973), Fissile Materials
- Section VII (1973), Test and Inspection Procedures
- Section V (1985), Requirements for Radioactive Materials and for Packagings and Packages
- Section VI (1985), Test Procedures of IAEA's regulations, and indicates for each requirement that either the DHTF complies with the standard or said standard is not applicable to the DHTF package (e.g., requirements for shielding). For those IAEA standards identical to regulations in 10 CFR 71, conformance is illustrated in the preceding eight chapters of this license application.

IAEA standards different from or in addition to Part 71 regulations are called out and/or expanded upon in Table 9.2 for the 1973 Edition. The same comparison is made in Table 9.4 to the 1985 Edition of the IAEA regulation. Many of these differences are inherent in, but not expressly written into, Part 71 requirements. For example, IAEA paragraph #232 stipulates that thermal protection shall remain effective during Normal Conditions Testing and the 30-foot drop and 40-inch puncture tests. While Part 71 does not contain such a written requirement, it is clear that the thermal protection must remain effective if the package is to survive the thermal test. Such logic can apply to others of the IAEA standards in Table 9.2 and 9.4 (e.g., #236, #238, #704, etc.).

Whether the IAEA standard is inherent in Part 71 or not, however, the DHTF conforms to all standards for both Type A and Type B(U) Packages.

9.3 Appendix

- Table 9.1 - 1973 IAEA Packaging and Package Design Requirements
- Table 9.2 - Applicable 1973 IAEA Standards Different from or in Addition to 10 CFR 71
- Table 9.3 - 1985 IAEA Packaging and Package Design Requirements
- Table 9.4 - Applicable 1985 IAEA Standards Different From or in Addition to 10 CFR 71.

TABLE 9.1

IAEA PACKAGING AND PACKAGE DESIGN REQUIREMENTS

IAEA[1]		NRC[2]	Compliance[3]	Comments
All Packages:				
201		-	Yes	
202		-	-	Not applicable to DHTF
203		-	Yes	
204		71.45(a)	-	Not applicable to DHTF
205		71.45(a)	-	Not applicable to DHTF
206		-	Yes	
207		-	Yes	
208		-	-	Not applicable to DHTF
Additional for LLSRM Packages:				
209		-	-	Not applicable to DHTF
Additional for Type A Packages:				
210		71.43(a)	Yes	
211		71.43(b)	Yes	
212		-	Yes	
213		(4)	Yes	IAEA Temp. range is 40°C to +70°C; NRC Temp. range is -40°C to +38°C
214		-	Yes	
215		71.71(c)(5)	Yes	
216		71.43©	Yes	
217		-	-	Not Applicable to DHTF
218		-	Yes	
219		71.43(d)	Yes	
220		-	-	Not Applicable to DHTF
221		71.71(c)(3)	Yes	
222		71.43(e)	-	Not Applicable to DHTF
223		-	-	Not Applicable to DHTF
224		71.45(b)	-	Not Applicable to DHTF
225	(a)	71.43(f)	Yes	
225	(b)	71.43(f)	Yes	

226	(a)	-	-	Not Applicable to DHTF
226	(b)	-	-	Not Applicable to DHTF
226	(c)	-	-	Not Applicable to DHTF
227		-	-	Not Applicable to DHTF

Additional for Type B(U) Packages:

228		71.51(a)	Yes	
229		-	Yes	See Note (5)
230	(a)	-	-	Not Applicable to DHTF
230	(b)	71.43(g)	Yes	
231		71.71(c)(1)	-	A condition, not a requirement
232		-	Yes	
233	(a)	71.51(a)(1)	Yes	
233	(b)	71.51(a)(2)	Yes	IAEA: A2 X 10^{-3}per wk; NRC: A2 per week
234		71.51(b)	Yes	
235		71.43(h)	Yes	
236		-	Yes	
237		-	-	Not Applicable to DHTF
238		-	Yes	
239		-	Yes	
240		71.43(g)	Yes	
241		-	-	Not Applicable to DHTF

Nuclear Safety:

602		71.55(b)	Yes	
603		71.55(b)	-	Not applicable to DHTF
604	(a)	71.4	-	
604	(b)	71.4	Yes	
604	©	71.4	Yes	

Fissile Packages:

615		71.55(d)	Yes	
616		-	Yes	
617		-	-	A condition, not a requirement
618		71.55(e)	Yes	
619	(a)	71.59(b)(1)	Yes	
619	(b)	71.59(b)(2)	Yes	

Package Tests:

701		71.41(a)	Yes	
702		(5)	Yes	IAEA: 38°C; NRC:least favorable between -29°C and + 38°C
703		-	Yes	
704		-	Yes	
705		-	Yes	
706		-	Yes	
707		-	Yes	
708		(6)	Yes	
709		71.71(a)	Yes	
710		-	Yes	
711		71.71(c)(6)	Yes	
712	(a)	71.71(c)(7)	Yes	
712	(b)	71.71(c)(7)	Yes	
712	©	71.71(c)(8)	-	Not Applicable to DHTF
712	(d)	71.71(c)(8)	-	Not Applicable to DHTF
713		71.71(c)9)	Yes	
714		71.71(c)(10)	Yes	
715		-	-	Not Applicable to DHTF
716		-	-	Not Applicable to DHTF
717		-	-	Not Applicable to DHTF
718		71.73(a)	Yes	
719	(a)	71.73(c)(1)	Yes	
719	(b)	71.73(c)(2)	Yes	
720		71.73(c)(3)	Yes	
721		71.73(c)(5)	Yes	
722		71.73(c)(4)	-	Not Applicable to DHTF
723		71.73(c)(4)	-	Not Applicable to DHTF
724		71.73(c)(4)	-	Not Applicable to DHTF
725		-	-	Not Applicable to DHTF

Notes:

(1) Paragraph in the IAEA Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition (As Amended)
(2) 10 CFR Part 71 regulations in effect as of 15 September 85 which correspond to the listed IAEA paragraph.
(3) Compliance of the DHTF to the listed IAEA paragraph.
(4) 71.71(b); 71.71(c)(1), and (c)(2); 71.73(b).
(5) 71.71(b); 71.73(b).
(6) 71.71(c)(7); 71.71(c)(8); 71.73(c)(1); 71.73(c)(2)

TABLE 9.2

Applicable IAEA Standards [a] Different From or in Addition to 10 CFR 71[b]

Para. ©	Compliance (d)	Requirement
All Packages:		
201	Yes	Package can be easily handled and properly stored
203	Yes	Designed to enable safe handling by mechanical means.
206	Yes	Designed to avoid, as far as practicable, the collection and retention of water.
207	Yes	External surfaces easily decontaminated
Additional for Type A Packages:		
212	Yes	External surfaces are free from pro-truding features
213	Yes	(e) Materials satisfactory over the range -40°C to +70°C
214	Yes	Welds in accordance with national standards
218	Yes	Containment system positive fastening device that is independent of any other part of the packaging.
Additional for Type B(U) Packages:		
229	Yes	Radiation levels increase ≤100-fold due to Normal Conditions and Accident Conditions Testing.
232	Yes	Thermal protection remains effective during drop and puncture tests.
236	Yes	No pressure relief for the containment system during Normal and Accident Conditions Testing
238	Yes	Containment system pressure not to exceed minimum yield strength during thermal test.
239	Yes	Maximum NOP ≤100 psig.

Package Tests:

702	Yes	(f) Ambient temperature of 38°C for testing
704	Yes	Pre-testing inspection of specimens
705	Yes	Containment system clearly specified
706	Yes	External features of specimen

Notes:

(a) IAEA Regulations for the Safe Transport of Radioactive Materials - 1973 Revised Edition (As Amended)

(b) 10 CFR Part 71 regulations in effect as of 15 Sept 85.

© IAEA Paragraph.

(d) Compliance of the DHTF package to this regulation.

(e) NRC regulations 71.71(c)(1) and (c)(2) specify a range of -40°C to +38°C.

(f) NRC regulations 71.71(b) and 71.73(b) stipulate the selection of the least favorable ambient temperature between -29°C and +38°C.

TABLE 9.3

1985 IAEA PACKAGING AND PACKAGE DESIGN REQUIREMENTS

IAEA [1]	NRC [2]	Compliance [3]	Comments
All Packages:			
505	-	Yes	
506	71.45(a)	-	Not applicable to DHTF
507	71.45(a)	-	Not applicable to DHTF
508	-	Yes	
509	-	Yes	
510	-	-	Not applicable to DHTF
511	-	Yes	
512	-	Yes	
513	-	-	Not applicable to DHTF
514/407	-	-	Not applicable to DHTF
Additional for Type A Packages:			
524	-	Yes	
525	71.43(a)	Yes	
526	71.43(b)	Yes	
527	71.45(b)	-	Not applicable to DHTF
528	(5)	Yes	IAEA Temp. range is -40°C to + 70°C; NRC Temp. range is 40°C to + 38°C
529	-	Yes	
530	71.43©	Yes	
531	-	-	Not applicable to DHTF
532	-	Yes	
533	-	-	Not applicable to DHTF
534	71.71(c)(3)	Yes	
535	71.43©	-	Not applicable to DHTF
536	-	-	Not applicable to DHTF
537 (a)	71.43(f)	Yes	
537 (b)	71.43(f)	Yes	
538	-	-	Not applicable to DHTF
539	-	-	Not applicable to DHTF
540	-	-	Not applicable to DHTF

Additional for Type B Packages:

541		71.51(a)	Yes	
542		-	Yes	
543		-	-	Not applicable to DHTF
544		-	-	Not applicable to DHTF
545		-	-	A condition, not a requirement
546		-	-	A condition, not a requirement
547		-	Yes	
548(b)	71.51(a)(1)	Yes		
548(b)	71.51(a)(2)	Yes		

Type B(U) Packages:

549		-	Yes	
550		-	-	Not applicable to DHTF
551		71.51(b)	Yes	
552		-	Yes	
553		-	Yes	
554		-	Yes	
555		71.43(g)	Yes	IAEA limit is 85°F NRC limit is 82°C
556		-	Yes	

Fissile Material Packages:

559		-	Yes	
560		-	-	Not applicable to DHTF
561		-	Yes	
562		-	Yes	
563	(a)	71.55(d)	Yes	
563	(b)	71.55(d)	Yes	
563	©	71.55(d)	Yes	
564		71.55(d)	-	A definition, not a requirement
565		-	-	A condition, not a requirement
566	(a)	71.55(e)	Yes	
565	(b)	71.55(e)	Yes	
567	(a)	71.59(b)(1)	Yes	
567	(b)	71.59(b)(2)	Yes	
568		-	-	Not applicable to DHTF

Package Tests:

601		71.41(a)	Yes	
602		-	-	A condition, not a requirement
614		-	Yes	
615		-	Yes	
616		-	Yes	
617		-	Yes	
618		-	Yes	
619		71.41(a)	Yes	
620		-	Yes	
621		71.71(c)(6)	Yes	
622	(a)	71.71(c)(7)	Yes	
622	(b)	71.71(c)(7)	Yes	
623		71.71(c)(9)	Yes	
624		71.71(c)(10)	Yes	
626		71.73(a)	Yes	
627	(a)	71.73(c)(1)	Yes	
627	(b)	71.73(c)(2)	Yes	
628		71.73(c)(3)	Yes	(4)
629		71.73(c)(5)	Yes	

Notes:

(1) Paragraph in the IAEA Regulations for the Safe Transport of Radioactive Materials, 1985 Edition

(2) 10 CFR Part 71 regulations in effect as of 15 September 85

(3) Compliance of the DHTF to the listed IAEA paragraph

(4) Burn pan used allowed a distance of 2 to 2.5 feet beyond the external surface of the drum.

(5) 71.71(b); 71.71(c)(1) and (c)(2); 71.73(b).

TABLE 9.4

Applicable 1985 IAEA Standards[a] Different From or in Addition to 10 CFR 71[b]

Para. ©	Compliance (d)	Requirement
All Packages:		
505	Yes	Package can be easily handled and properly stored
508	Yes	External surfaces easily decontaminated
509	Yes	Designed to avoid, as far as practicable, the collection and retention of water
Additional for Type A Packages:		
528	Yes	(e) Materials satisfactory over the range -40°C to +70°C
529	Yes	Welds in accordance with national standards
532	Yes	Containment system positive fastening device that is independent of any other part of the packaging.
Additional for Type B(U) Packages:		
542	Yes	Radiation levels not exceed 1 rem/hr. due to Accident Conditions Testing.
547	Yes	Thermal protection remains effective during normal conditions testing and 30' drop and 40" puncture tests.
552	Yes	No pressure relief for the containment system during Normal and Accident Conditions Testing
553	Yes	Containment system pressure not to exceed minimum yield strength during normal and accident conditions testing.
554	Yes	Maximum NOP ≤100 psig.

Package Tests:

614	Yes	Pre-testing inspection of specimens
615	Yes	Containment system clearly specified
616	Yes	External features or specimen
628	Yes	Specifically calls for hydrocarbon fuel/air at 800°C for 30 minutes

Notes:

(a) IAEA Regulations for the Safe Transport of Radioactive Material – 1985 Edition.

(b) 10 CFR Part 71 regulations in effect as of 15 Sept 85.

(c) IAEA Paragraph.

(d) Compliance of the DHTF package to this regulation.

(e) NRC regulations 71.71(c)(1) and (c)(2) specify a range of -40°C to +38°C.

APPENDIX

Applicable IAEA Standards[a] Different From or in Addition to 10 CFR 71[b]

Para.(c)	Compliance(d)	Requirement
All Packages:		
201	Yes	Package can be easily handled and properly stored
203	Yes	Designed to enable safe handling by mechanical means.
206	Yes	Designed to avoid, as far as practicable, the collection and retention of water.
207	Yes	External surfaces easily decontaminated.
Additional for Type A Packages:		
212	Yes	External surfaces are free from pro-truding features
213	Yes	(e) Materials satisfactory over the range -40°C to +70°C
214	Yes	Welds in accordance with national standards
218	Yes	Containment system positive fastening device that is independent of any other part of the packaging.
Additional for Type B(U) Packages:		
229	Yes	Radiation levels increase ≤ 100-fold due to Normal Conditions and Accident Conditions Testing.
232	Yes	Thermal protection remains effective during drop and puncture tests.

236	Yes	No pressure relief for the containment system during Normal and Accident Conditions Testing
238	Yes	Containment system pressure not to exceed minimum yield strength during thermal test.
239	Yes	Maximum NOP ≤100 psig.

Package Tests:

702	Yes	(f) Ambient temperature of 38°C for testing
704	Yes	Pre-testing inspection of specimens
705	Yes	Containment system clearly specified

Notes:

(a) IAEA Regulations for the Safe Transport of Radioactive Materials - 1973 Revised Edition (As Amended)

(b) 10 CFR Part 71 regulations in effect as of 15 Sept 85.

(c) IAEA Paragraph.

(d) Compliance of the DHTF package to this regulation.

(e) NRC regulations 71.71(c)(1) and (c)(2) specify a range of -40°C to +38°C.

(f) NRC regulations 71.71(b) and 71.73(b) stipulate the selection of the least favorable ambient temperature between -29°C and +38°C.